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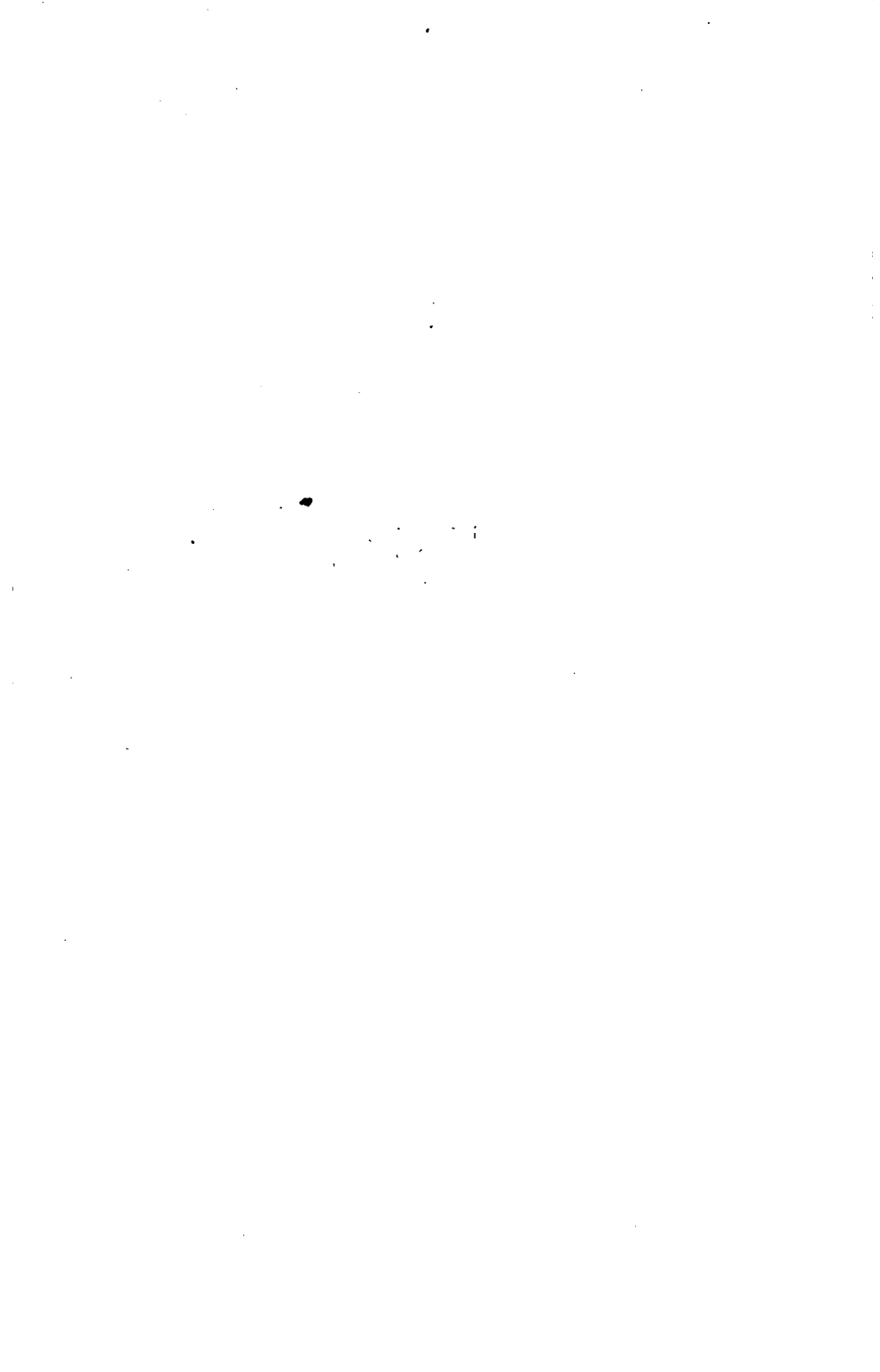
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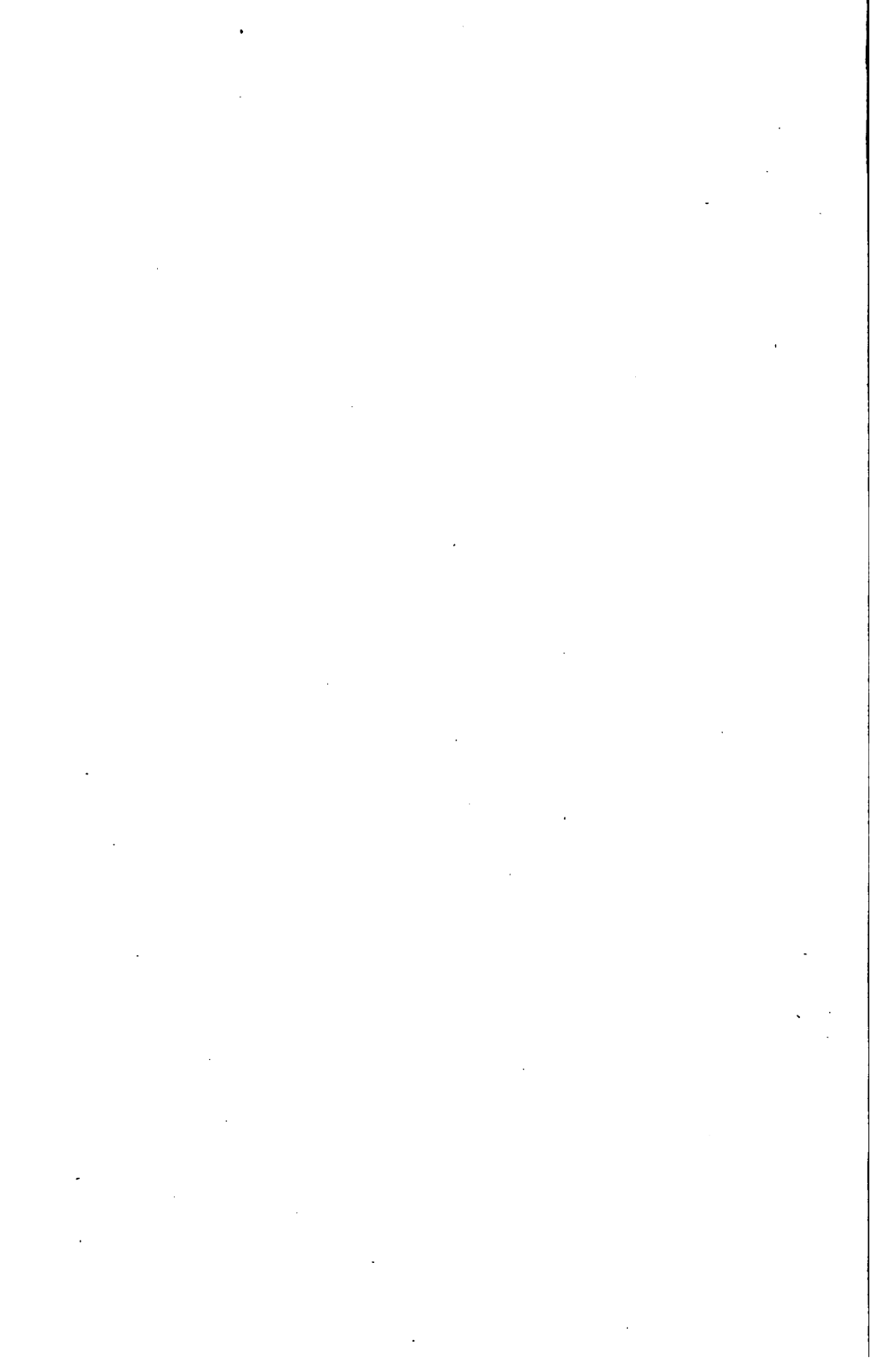
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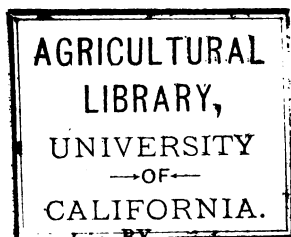
OCCASIONAL LECTURES,

AND

OTHER DISCOURSES,

ON

AGRICULTURAL CHEMISTRY.



JOSEPH HENRY GILBERT, M.A., LL.D., F.R.S., V.P.C.S., &c.



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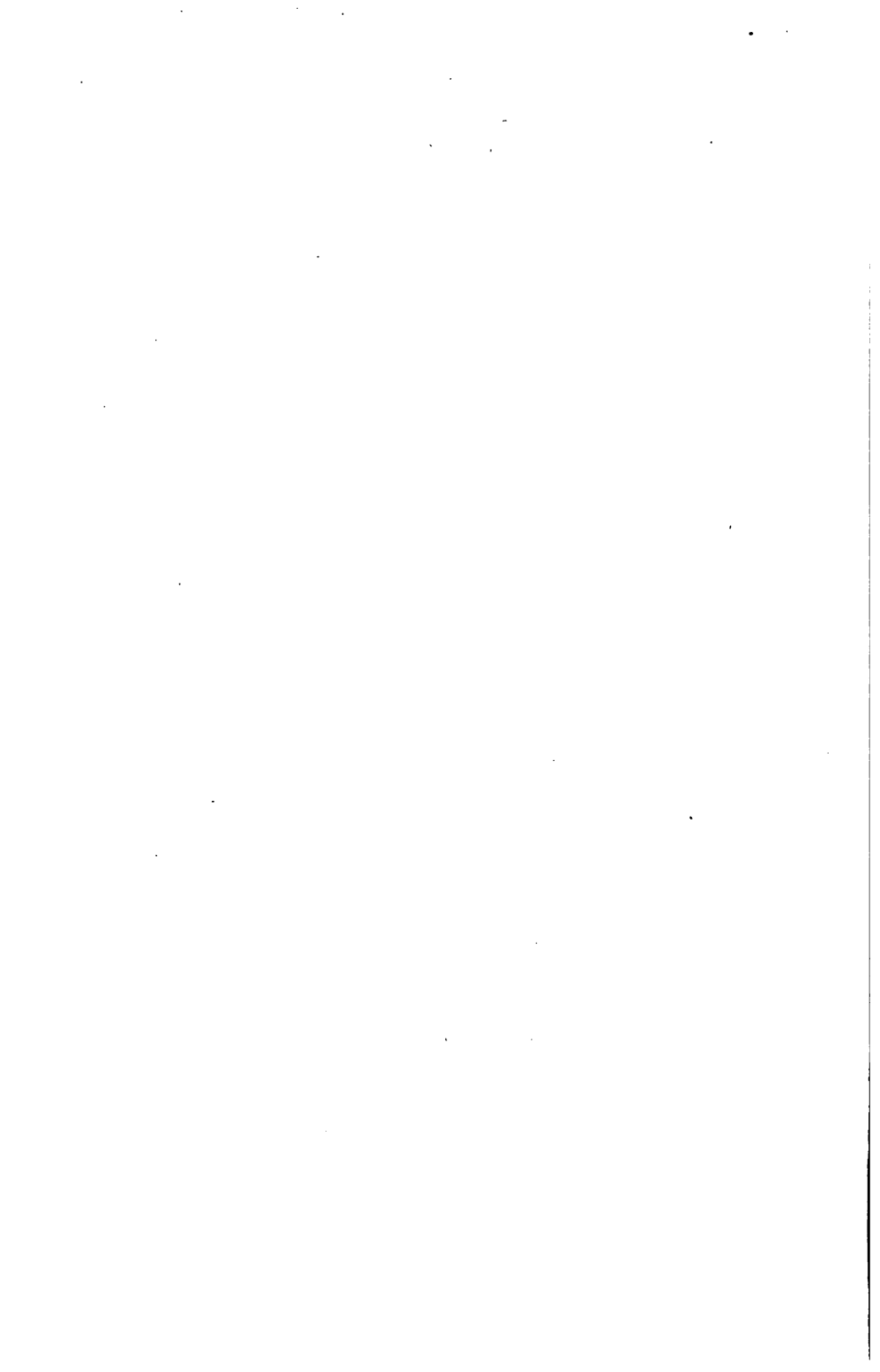
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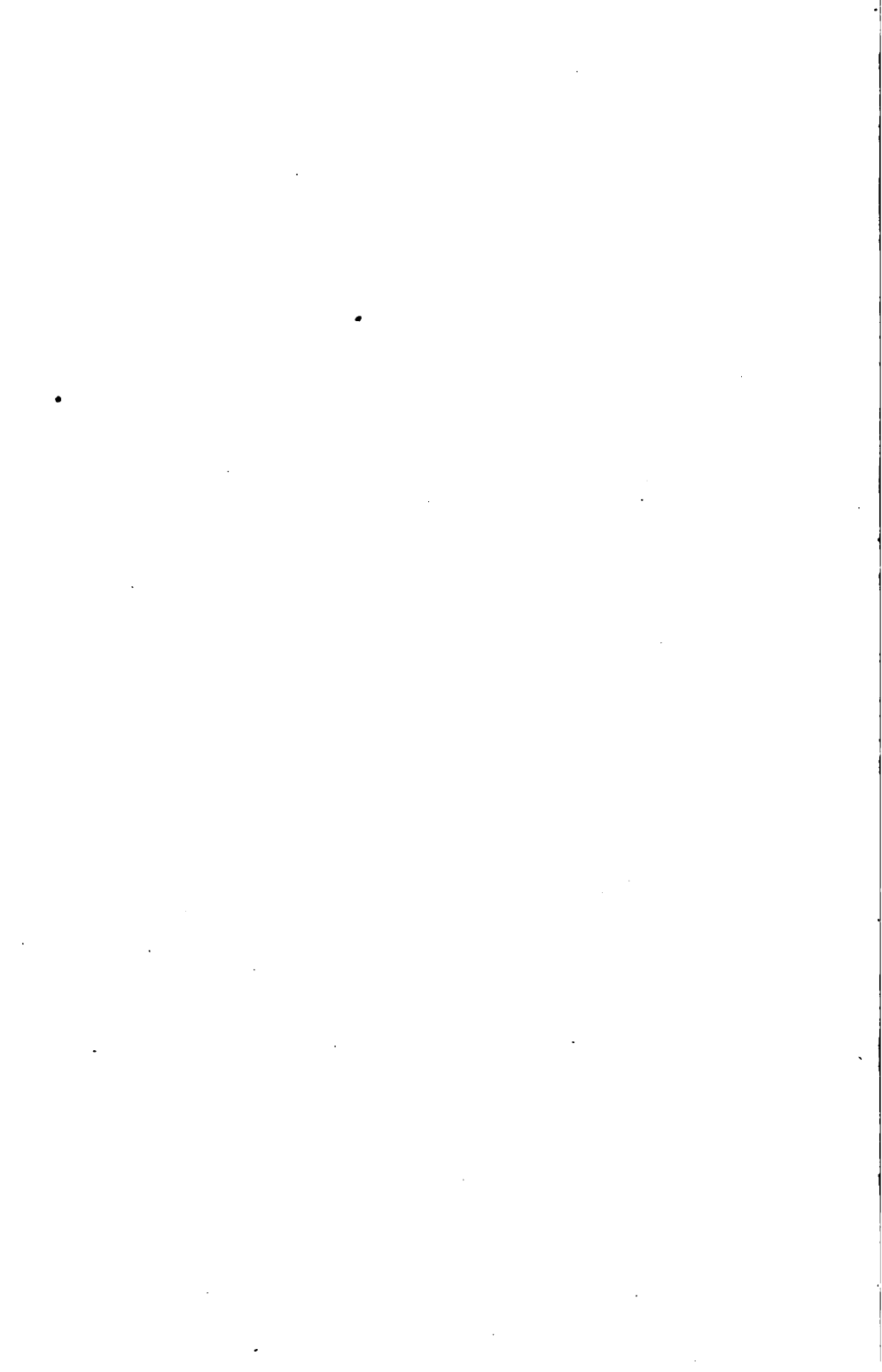
ON SOME POINTS IN CONNECTION WITH VEGETATION.

BEING AN ADDRESS DELIVERED AT SOUTH KENSINGTON,
IN THE CHEMICAL SECTION OF THE
SCIENCE CONFERENCES,

May 18, 1876.

BY DR. J. H. GILBERT, F.R.S., F.L.S., F.C.S.

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ON SOME POINTS IN CONNECTION WITH VEGETATION.

By Dr. J. H. GILBERT, F.R.S., F.L.S., F.C.S.

The subject of vegetation is such a very wide one, and might be treated of in so many different ways, that it seems desirable to state at the outset what is the scope, and what are the limits, of the discussion which I propose to bring before you. I propose, then, to confine attention almost exclusively to the question of the sources of the nitrogen of vegetation in general, and of agricultural production in particular. I propose further to treat of this subject mainly in the aspects in which it has forced itself upon the attention of Mr. Lawes and myself during the now thirty-three years of our agricultural investigations; and, also, in so far as it illustrates, and is illustrated by, the objects contributed by Mr. Lawes to the Exhibition around us.

Before entering upon the special subject matter of my discourse, I must claim the indulgence of those present who are already well acquainted with the main facts of the chemistry of vegetation, whilst I call attention, very briefly, to some rather elementary matters, with a view of rendering what has to follow the more intelligible to any who may be less fully informed on the subject.

When a vegetable substance is burnt—as a familiar instance, let us say tobacco, for example—the greater part of it is dissipated, but there remains a white ash. The ashes of crude or unripe vegetable substances are found on analysis to contain most, or all, of the following constituents, namely:—

Oxide of iron, oxide of manganese, lime, magnesia, potass, soda, phosphoric acid, sulphuric acid, chlorine, and silica.

Rarer substances than these are also sometimes found. Now, much has of late years been established in regard to the occurrence, and the offices, of some of these substances in plants; but I do not propose to touch upon the questions herein involved. It will suffice further to say in regard to these incombustible, or “mineral” constituents, that the ash of one and the same description of plant, growing on different soils, may, so long as it is in the growing or immature state, differ very much in composition. Again, the ashes of different species, growing on the same soil, will differ very widely in the proportion of their several constituents. But it is found that the nearer we approach to

the elaboration of the final products of the plant—the seed, for example—the more fixed is the composition of ash of such products of one and the same species. In other words, there is very little variation in the composition of the ash of one and the same description of seed, or other final product, provided it be evenly and perfectly matured. This fact alone, independently of all that has been established of late years in regard to the office or function, so to speak of individual mineral constituents of plants, would be sufficient to indicate the essentialness of such constituents for healthy growth; and it is obvious that they must be provided *within the soil*.

But now as to the combustible constituents—the carbon, the hydrogen, the oxygen, and the nitrogen. Leaving out of consideration such exceptional cases as those brought to light in Mr. Darwin's beautiful investigation on insectivorous plants, and also the sources of the organic substance of fungi, and perhaps of some forced horticultural productions, it may be stated that the source of the carbon of vegetation generally is the carbonic acid existing in very small proportion, but in large actual amount, in the atmosphere; that the source of the hydrogen is water; and that the source of the oxygen may be either that in carbonic acid, or that in water. With regard to the nitrogen the case is, however, by no means so simple. Not that there are no questions still open for investigation in regard to the assimilation by plants of their incombustible or mineral constituents, or of their carbon, their hydrogen, and their oxygen; but those relating to the sources, and to the assimilation, of their nitrogen, are not only in many respects of more importance, but seem to involve greater difficulties in their solution.

What, then, are the sources of the nitrogen of vegetation? Are they the same for all descriptions of plants? Are they to be sought entirely in the soil? or entirely in the atmosphere? or partly in the one, and partly in the other?

As the combined nitrogen coming down from the atmosphere in rain, hail, snow, mists, fog, and dew, does undoubtedly contribute to the annual yield of nitrogen in our crops, let us first briefly consider what is known as to the amount of it annually so coming down over a given area of the earth's surface; and as we are here discussing the subject in England, I will adopt the English pound as the unit of weight, and the English acre as the unit of area. The following table shows the amount of nitrogen coming down as ammonia and nitric acid in the total rain, hail, snow, and some of the minor deposits

during the years 1853, 1855, and 1856, at Rothamsted (Herts), the nitric acid being in all cases determined by Mr. Way, and the ammonia in some cases by him, and in others by ourselves:—

TABLE I.
Combined Nitrogen in Rain and Minor Aqueous Deposits at Rothamsted.

	Nitrogen per acre, per annum, lbs.			
	1853.	1855.	1856.	Mean.
As ammonia	5·67	5·86	7·85	6·46
As nitric acid	(not determined)	0·77	0·73	0·75
Total		6·63	8·58	7·21

Numerous determinations of the ammonia and nitric acid in rain, and the other aqueous deposits, have been made in various parts of France and Germany, some in the vicinity of towns, and some in the open country. Of the latter, which are the most to our purpose, it may be stated that those of Boussingault at Liebfrauenberg, in Alsace, generally indicate a larger proportion of the nitrogen existing as nitric acid, and less as ammonia than our own; but, upon the whole, the observations in the two widely separated localities mutually confirm one another. Of the results of others, in other localities, some show about the same amount of combined nitrogen so deposited as our own, some, however, much more, and some much less, than ours; but the determinations on the Continent generally show a higher proportion of the total combined nitrogen to exist as nitrates than those in this country. It may be added, that numerous determinations of the combined nitrogen in rain, dew, &c., collected at Rothamsted, have much more recently been made by Professor Frankland, and his results, which are published in the "Sixth Report of the Rivers Pollution Commission," are substantially confirmatory of the earlier determinations, summarized in the foregoing Table, but upon the whole they indicate lower amounts. Lastly, M. Marié-Davy determined the ammonia in the rain, &c., collected at the Meteorological Observatory at Montsouris, Paris, during the last six months of 1875; and the amount of ammonia so coming down, even within the walls of Paris, only represented 5·25 lbs. of combined nitrogen per acre, or only 10·5 lbs. per acre, per annum. M. Marié-Davy did not make a complete series of determinations of the nitric acid in the meteoric waters, but his initiative results agree with the experiments of others in showing the amount of combined nitrogen so existing to be comparatively small.

Thus, the determinations hitherto made of the amount of combined nitrogen coming down in the measured aqueous deposits from the atmosphere, do not justify us in assuming that the quantity available from that source will exceed 8 or 10 lbs. per acre, per annum, in the open country, in Western Europe. It should be observed, however, that the amount of ammonia especially is very much greater in a given volume of the minor aqueous deposits than it is in rain; and there can be little doubt that there would be more ammonia deposited from them within the pores of a given area of soil, than on an equal area of the non-porous even surface of a rain gauge. How much, however, would thus be available to the vegetation of a given area beyond that determined in the collected and measured aqueous deposits, we have not the means of estimating with any certainty. On the other hand, numerous independent determinations, by both Dr. Voelcker and Dr. Frankland, of the nitric acid in the drainage-water collected from land at Rothamsted which had been many years unmanured, lead to the conclusion that there may be a considerable annual loss of nitrogen by the soil in that way.

The next point to consider is, what is the amount of nitrogen annually obtained over a given area, in different crops, when they are grown without any supply of it in manure. This point may be illustrated by the results obtained in the field experiments on Mr. Lawes' farm at Rothamsted, which have now been in progress for about a third of a century. Table 2, which follows, shows the yield of nitrogen per acre, per annum, in wheat, in barley, and in root crops, each grown for many years in succession on the same land, either without any manure, or with only a complex mineral manure, that is supplying no nitrogen.

TABLE II.

Yield of Nitrogen per acre, per annum, in Wheat, Barley, and Root Crops, at Rothamsted.

Crop, &c.	Condition of Manuring, &c.	Duration of Experiment.	Average Nitrogen per acre, per annum.
Wheat.	Unmanured	8 yrs. 1844-'51	lbs. 25.2
		12 yrs. 1852-'63	22.6
		12 yrs. 1864-'75	15.9
		24 yrs. 1852-'75	19.3
		32 yrs. 1844-'75	20.7
	Complex Mineral Manure ...	12 yrs. 1852-'63	27.0
		12 yrs. 1864-'75	17.2
		24 yrs. 1852-'75	22.1

TABLE II.—*continued.*

Crop, &c.	Condition of Manuring, &c.	Duration of Experiment.	Average Nitrogen per acre, per annum.	
Barley .	Unmanured	12 yrs. 1852-'63	lbs. 22'0	
		12 yrs. 1864-'75	14'6	
		24 yrs. 1852-'75	18'3	
	Complex Mineral Manure ...	12 yrs. 1852-'63	26'0	
		12 yrs. 1864-'75	18'8	
		24 yrs. 1852-'75	22'4	
Root Crops .	Complex Mineral Manure. }	Turnips ...	8 yrs. 1845-'52	42'0
		Barley ...	3 yrs. 1853-'55	24'3
		Turnips ...	15 yrs. 1856-'70 ¹	18'5
		Sugar-beet...	5 yrs. 1871-'75	13'1
		Total ...	31 yrs. 1845-'75	26'8

Bearing in mind what has been said as to the amount of combined nitrogen known to be annually deposited from the atmosphere, the figures in Table II. have great interest and significance. Thus, over a period of 32 years, the wheat has yielded an average of 20'7 lbs. of nitrogen, per acre, per annum, without manure. But if we look at the quantities yielded during the first 8, the next 12, and the last 12 years of that period, it is seen that there has been a gradual, but at the same time a considerable decline in the annual yield. From this it would appear probable that the nitrogen of the soil, derived from previous accumulations, is being gradually reduced. Whether or not the whole of the excess of yield over that available from the rain, and other measured aqueous deposits from the atmosphere, is due to previous accumulations within the soil, and is therefore inducing a gradual exhaustion of its stock of nitrogen to that extent, we have not conclusive evidence to show. Determinations of nitrogen in samples of the soil taken at different times during the course of the experiments do, indeed, show an appreciable reduction. It is probable, however, that a part of the excess of yield is due to condensation of ammonia within the pores of the soil, beyond that which would be deposited in rain, and in the dew and other minor deposits condensed on the non-porous even surface of a rain-gauge, as already referred to.

Excluding the first 8 years of the growth of wheat, it is seen that whilst over the next 24 years, 1852-1875, the wheat yielded 19'3 lbs.

¹ Thirteen years' crop—two years failed.

of nitrogen, per acre, per annum; the barley yielded an average of 18.3 lbs. over the same period. Again, during the first 12 of the 24 years, the wheat yielded 22.6 lbs., and the barley 22 lbs.; whilst, during the second 12 years, the yield in wheat was reduced to 15.9, and that in the barley to 14.6 lbs. The similarity in the yield of nitrogen over the same periods in these two closely allied crops, growing in different fields, is very striking, though, upon the whole, the indication is that the autumn-sown wheat has accumulated more than the spring-sown barley.

It is next to be observed that the annual use of a complex mineral manure has but very slightly increased the yield of nitrogen in either of these gramineous crops; and it is probable that the increased yield, such as it is, is derived from the previous accumulations within the soil, and not from atmospheric sources.

To sum up the evidence in regard to the sources of the nitrogen of these two typical gramineous plants, when none of it is supplied to them by manure, though it is not conclusively shown whence the whole of it is derived, it would at any rate appear probable, that it may be accounted for by the combined nitrogen coming down in rain, and in the other measured aqueous deposits from the atmosphere, by the condensation of the ammonia of the air within the pores of the soil, and by the previous accumulations within the soil.

Let us now consider what is the yield of nitrogen by plants of other natural families, and first of all by certain so-called "root-crops"—turnips of the natural order cruciferae, and sugar beet of the order chenopodiaceae. On this point we have the experience of 31 years, excepting that during three of those years barley was grown without any manure in order to equalise the condition of the land as far as possible before re-arranging the manuring, and during 2 other years the turnips failed and there was no crop.

It should be premised that when root-crops are grown without manure of any kind, there is after a few years scarcely any produce at all; and hence the results recorded in the table are those obtained by the use of mineral manures, but without any supply of nitrogen. It is seen that during the first 8 years of turnips, there was an average yield of 42 lbs. of nitrogen per acre per annum. During the next 3 years barley yielded 24.3 lbs. annually. During the next 15 years, 13 with Swedish turnips, and two without any crop, there was a yield of 18.5 lbs. per acre annually. During the last 5 years sugar-beet yielded 13.1 lbs. per acre per annum. Lastly, over the whole 31 years,

during which there were 3 crops of barley, 2 years without any crop, 21 years of turnips, and 5 of sugar-beet, the average annual yield was 26·8 lbs. of nitrogen.

Here, then, we have a reduction to less than one-third during the later compared with the earlier years, and to a lower point than even with either wheat or barley; though, during the whole period, the annual yield is higher than with either of the two gramineous crops. It may be mentioned that we have other experimental evidence showing that the so-called "root-crops" exhaust at any rate the superficial layers of the soil of their available supplies of nitrogen, more completely than perhaps any other crop. It may further be added that the surface soil has shown during recent years a lower percentage of nitrogen than that of any of the other experimental fields. We have fair grounds for concluding, therefore, that if in the cases of the wheat and the barley the nitrogen yielded beyond that retained by the soil from the direct measurable aqueous deposits, together with that condensed within the pores of the soil, from the atmosphere, be derived from previous accumulations within the soil, so also may the excess of yield by the so-called "root-crops" be accounted for.

We now come to the consideration of the yield of nitrogen when plants of the *leguminous* family are separately grown, or when they, and plants of some other families, are grown in alternation, or in association, with the gramineæ. Table III. shows the results obtained with beans, and with clover; with clover and barley grown in alternation; and with turnips, barley, clover or beans, and wheat, grown in an actual course of rotation.

TABLE III.

Yield of Nitrogen per Acre per Annum in Beans, in Red Clover, and in Rotation.

Crops, &c.	Conditions of Manuring, &c.	Duration of Experiment.	Average Nitrogen per acre, per annum.
			lbs.
Beans	Unmanured	12 yrs. 1847-'58	48·1
		12 yrs. 1859-'70 ⁽¹⁾	14·6
		24 yrs. 1847-'70	31·3
	Complex Mineral Manure ...	12 yrs. 1847-'58	61·5
		12 yrs. 1859-'70 ⁽¹⁾	29·5
		24 yrs. 1847-'70	45·5

(1) 9 years Beans, 1 year Wheat, 2 years Fallow.

TABLE III.—*continued.*

Crops, &c.	Conditions of Manuring, &c.	Duration of Experiment.	Average Nitrogen per acre, per annum.
Clover	Unmanured	22 yrs. 1849-'70 ⁽¹⁾	30·5
	Complex Mineral Manure ...	22 yrs. 1849-'70 ⁽¹⁾	39·8
Barley Clover	} Unmanured {	1 yr. 1873	37·3
		1 yr. 1873	151·3
Barley	Unmanured ... { After Barley After Clover	1 yr. 1874	39·1
		1 yr. 1874	69·4
	Barley after Clover more than after Barley		30·3
Rotation 7 Courses	{ 1 Turnips 2 Barley 3 Clover or Beans 4 Wheat }	Unmanured	28 yrs. 1848-'75
		Superphosphate ...	28 yrs. 1847-'75
			45·2

Referring first to the results obtained with beans, the table shows that without manure there was an annual yield over the first 12 years, 1847—1858, of 48·1 lbs. of nitrogen. Over the next 12 years, 1859—1870, it was reduced to 14·6 lbs. per acre per annum. Still, over the whole period of 24 years, we have an annual yield of 31·3 lbs., or more than one and a half time as much as in either wheat or barley.

In the case of wheat and barley it was seen that a mixed mineral manure increased the yield of nitrogen to a very small degree only. Not so in the case of the leguminous crop, beans. During the first 12 years a complex mineral manure, containing a large amount of potass—I call attention to this fact because we have abundant evidence that it is the potass chiefly that is effective—gave 61·5 lbs. of nitrogen per acre per annum against 48·1 lbs. obtained over the same period without manure. During the next 12 years, the potass manure gave 29·5 lbs. against scarcely half as much, or 14·6 lbs. without the potass manure. And finally, during the whole period of 24 years, the potass manure has given 45·5 lbs. of nitrogen per acre per annum, against 31·3 lbs., or only about two-thirds as much, without manure; and we have more than twice as much yielded by a potass manure over a period of 24 years with beans than with either wheat or barley.

(1) 6 years Clover, 1 year Wheat, 3 years Barley, 12 years Fallow.

Before calling attention to the figures relating to another leguminous crop—red clover—it should be mentioned that leguminous crops generally are, and clover in particular is, extremely sensitive to adverse climatal circumstances ; but clover is pre-eminently sensitive to soil conditions also. Indeed, it is a fact well recognised in agriculture, that few soils can be relied upon to grow a good crop of clover oftener than once in about 8 years ; and many soils will not yield it so frequently. It will not excite surprise, therefore, that in attempting to grow clover year after year on the same land, we have only succeeded in getting any crops, and some of those poor ones, in 6 years over a period of 22. Indeed, the plant failed seven times out of eight during the winter and spring succeeding the sowing of the seed ; when, in some cases a crop of whcat or barley was taken, and in others the land was left fallow. Hence, over a period of 22 years we have had only 6 years of clover, one of wheat, three of barley, and twelve of fallow. Still, the annual yield of nitrogen over the 22 years was 30·5 lbs. without any manure, and 39·8 lbs., or nearly one-third more, by mineral manure containing potass. Unfavourable as was this experiment in an agricultural point of view, still it is seen that the influence of the interpolation of this leguminous crop has greatly increased the yield of nitrogen compared with that obtained in either wheat or barley grown continuously ; and that, unlike the result with those crops, a potass manure has here again, as with beans, greatly increased the yield.

Without attempting for the moment to discuss the probable source or sources of this greatly increased yield of nitrogen by leguminous as compared with gramineous crops, I will simply here remark in passing that we have no evidence leading to the conclusion that this increased assimilation is at the expense of the nitrogen existing at any rate in the upper layers of the soil. In fact, such initiative results as we have relating to the nitrogen in the soil of the experimental bean field, would rather lead to the conclusion that the better the crop has grown, and the more nitrogen it has assimilated, the richer rather than the poorer in nitrogen (as indicated by the soda-lime method) has the surface soil become. To this point, however, we shall have to recur presently ; but in the meantime let us first refer to the yield of nitrogen in other cases in which leguminous crops have been interpolated with others.

It is, indeed, well known that the growth and removal of a highly nitrogenous leguminous crop is one of the best possible preparations for the growth of a gramineous corn crop, which characteristically

requires nitrogenous manuring. A striking illustration of this apparent anomaly is afforded in the results next in order recorded in the Table III.

After the growth of six corn crops in succession by artificial manures alone, barley was grown without manure in 1873 on one portion of the same land; and on another portion clover was grown. It is calculated that there were taken off in the barley 37.3 lbs. of nitrogen, and in the three cuttings of clover 151.3 lbs. Yet, in the next year, 1874, barley succeeding the barley gave 39.1 lbs., and barley succeeding the clover gave 69.4 lbs. of nitrogen; or 30.3 lbs. more after the removal of 151.3 lbs. in clover than after the removal of 37.3 lbs. in barley. Nor was this remarkable result to be explained by either accident or error. For, determinations of nitrogen in four separately taken samples of the soil, in the mixture of the four, and in the mixture of six others, taken from each plot, and at different depths, all concurred in showing an appreciably higher percentage of nitrogen, especially in the surface soil, 9 inches deep, of the land from which the clover had been removed than in that from which the barley had been taken; and this was so, although, in every case, all visible vegetable debris had been carefully picked out. Here, then, the surface soil at any rate was positively enriched in nitrogen (determinable by soda-lime) by the growth and removal of a very highly nitrogenous crop. It may be mentioned that Dr. Voelcker has obtained results of a similar character.

The results next to be considered are those obtained in an actual four-course rotation of crops—namely, turnips, barley, clover or beans, and wheat. The experiments have been conducted through seven such courses; that is to say, over a period of twenty-eight years. One portion of the land, the results relating to which are given in the table, has been entirely unmanured during the whole of that period, and the other has received super-phosphate of lime alone, once every four years—that is to say, for the turnips commencing each course; but it has received no other manure throughout the 28 years, either mineral or nitrogenous.

Under these conditions—that is with a turnip crop and a leguminous crop interpolated with two gramineous crops—we have, without manure of any kind, an average of 36.8 lbs. of nitrogen yielded per acre, per annum; or not far from twice as much as was obtained with either of those cereal crops, wheat or barley, grown consecutively. With super-phosphate of lime alone, which, in a striking degree increased the yield of nitrogen in the turnips, reduced it in the succeeding barley, increased it greatly in the leguminous crops, and slightly in

the wheat immediately following them, we have the average annual yield of nitrogen raised to 45·2 lbs. per acre, per annum, over the 28 years; or to more than double that obtained by wheat or barley grown continuously by mineral manures alone. And it may be observed that where, in adjoining experiments, no leguminous crop was grown between the barley and the wheat, but the land was fallowed instead, the total yield of nitrogen in the rotation was very much less: the wheat succeeding the fallow yielding very little more nitrogen than that succeeding the leguminous crops which had removed so much of it. In other words, the removal of the most highly nitrogenous crops of the rotation—beans or clover—has been succeeded by a growth of wheat, and assimilation of nitrogen by it, almost as great as when it has succeeded a year of fallow—that is to say, a period of accumulation from external sources, and no removal by crops.

One other illustration must be given of the power of plants of the leguminous and some other families to assimilate more nitrogen over a given area than those of the gramineous family. But before entering upon the bearing of the results in question on this particular point, it will be necessary to digress a little to call special attention to the conditions of the experiments under which the results were obtained; and it is the more desirable to do this, since the most important of Mr. Lawes' contributions to this Exhibition is an illustration of the results I am about to refer to.

I must here forestall a little what I shall have to refer to more fully further on, as to the effects of characteristically different manuring substances on crops belonging to different botanical families. I will say briefly, then, that it is found that nitrogenous manures have generally a very striking effect in increasing the growth of gramineous crops grown separately on arable land, such as wheat, barley, or oats, all of which contain a comparatively small percentage of nitrogen, and, as has been illustrated, assimilate a comparatively small amount of it over a given area when none is supplied to them in manure. The highly nitrogenous leguminous crops, on the other hand, such as beans, peas, clover, and others, are by no means characteristically benefited by the use of direct nitrogenous manures, such as ammonia-salts or nitrates, though nitrates act much more favourably than ammonia-salts. Again, whilst, under equal conditions of soil and seasons, mineral without nitrogenous manures increase comparatively little the poor-in-nitrogen gramineous crops that are grown separately, such manures, and especially potass-manures, as has been seen, increase

in a striking degree, the growth of crops of the leguminous family grown separately, and coincidently the amount of nitrogen they assimilate over a given area.

✓ Such, then, is the result obtained in the separate growth, on arable land, of individual plants of the different families. Now, in the mixed herbage of permanent grass land, we may have fifty, or even many more species growing together, representing nearly as many genera, and perhaps eighteen or twenty natural orders or families. Of these, the gramineæ generally contribute the largest proportion of the herbage; and, on good grass land, if the leguminosæ do not come second, they are at any rate prominent. The degree in which other orders are represented may be very various indeed, according to soil, locality, season, and other circumstances. In Mr. Lawes' park, at Rothamsted, nearly eighty species have been observed; but of many only isolated specimens, and it may be stated generally that about fifty species are so prominent as to be found in a carefully averaged sample of the hay grown without manure.

Experiments on the influence of different manures on this mixed herbage were commenced in 1856; at which time the herbage was apparently pretty uniform over the whole area selected. About twenty plots, from one-quarter to one-half an acre each, were marked out, of which two have been left continuously without manure, and each of the others has received its own special manure, and as a rule the same description year after year—and the experiments have now been conducted over a period of twenty years.

Under this varied treatment, changes in the flora, so to speak, became apparent even in the first years of the experiments; and three times since their commencement, at intervals of five years—namely, in 1862, 1867, and 1872—a carefully averaged sample of the produce of each plot has been taken and submitted to careful botanical separation, and the percentage, *by weight*, of each species in the mixed herbage determined. Partial separations have also been made in other years.

Mr. Lawes has contributed a large case of specimens to the exhibition, which shows the botanical composition of the herbage on twelve selected plots in the seventeenth season of the experiments (1872). The quantities of the different plants there exhibited represent the relative proportion, by weight, in which each species was found in the mixed produce of the different plots; and the whole illustrates in a striking manner the domination of one plant over another, under the influence of different manures, applied year after year on the same plot.

The general results of the experiments may be briefly summarised as follows :—

The mean produce of hay per acre per annum has ranged, on the different plots, from about 23 cwt. without manure to about 64 cwt. on the plot the most heavily manured.

The number of species found has generally been about 50 on the unmanured plots, and has been reduced to an average of only 20, and has sometimes been less, on the most heavily manured plots.

Species belonging to the order *Gramineæ* have, on the average, contributed about 68 per cent. of the weight of the mixed herbage grown without manure; about 65 per cent. of that grown by purely mineral manures (that is, without nitrogen); and about 94 per cent. of that grown by the same mineral manures, with a large quantity of ammonia-salts in addition.

Species of the order *Leguminosæ* have, on the average, contributed about 9 per cent. of the produce without manure, about 20 per cent. of that by purely mineral manures (containing potass), and less than 0·01 per cent. of that by the mixture of the same mineral manures and a large quantity of ammoniacal salts.

Species belonging to various other orders have, on the average, contributed about 23 per cent. of the produce without manure; about 15 per cent. of that by purely mineral manures, and only about 6 per cent. of that by the mixture of the mineral manures and a large amount of ammonia-salts.

Not only the amounts of produce, but the number and description of species developed, have varied very greatly between the extremes here quoted, according to the particular character or combination of manure employed, and to the character of the seasons, as is strikingly illustrated by the arrangement of the specimens in the case, which, however, it should be borne in mind, show the composition of the herbage on the selected plots in one particular season only—namely, in 1872.

Obviously, these few remarks can only very inadequately indicate the interest of these curious illustrations of the domination of one plant over another in the mixed herbage of permanent grass land. Nor do we pretend to be able to give a satisfactory explanation of the variations induced, founded on the obvious or recorded difference in above-ground or under-ground character or habit of growth of the individual species. The whole of the results—agricultural, chemical, and botanical—obtained during the twenty years of the experiments are, however, now in course of arrangement for publication; and that

we may not overlook such explanations as might be suggested from the point of view of the botanist and vegetable physiologist, as well as that of the chemist, we have associated with ourselves Dr. Masters in working up the botanical part of the inquiry; and I think Dr. Masters will agree with me in saying that much more has yet to be known of the difference in the physiological capability, so to speak, of the leaves of plants of different species, genera, and orders, and of the difference in the distribution, and in the feeding power, of the roots, before satisfactory explanations of the facts observed can be given. Surely, a wide field of investigation for the botanist and vegetable physiologist is here opened up to view!

Let us now recur to the question of the various amounts of nitrogen assimilated over a given area by plants of different natural orders, and call attention to the facts bearing upon the point which these experiments on the mixed herbage of grass land have supplied.

In Table IV. is shown the average produce (in the condition of hay) in lbs., per acre, per annum, over 20 years, of herbage of the gramineous family, of herbage of the leguminous family, and of herbage of other orders, calculated according to the mean percentage of each of these, determined in separations at six periods, namely in 1862, 1867, 1871, 1872, 1874, and 1875, in samples of the produce of four of the plots which have received no nitrogenous manure from the commencement; and there is also given, by the side of these results, the average annual yield of nitrogen per acre over the first 10, the second 10, and the total period of 20 years, in each case.

TABLE IV.

Yield of Nitrogen in the Mixed Herbage of Permanent Grass-land at Rothamsted.

Plots.	Conditions of Manuring.	Average Produce per acre per annum, 20 years, 1856-1875, according to Mean per cent. at 6 periods 1862, '67, '71, '72, '74, '75.			Average Nitrogen per Acre per annum.		
		Grami- neæ.	Legumi- nosæ.	Other Orders.	10 years 1856- 1865	10 years 1866- 1875	20 years 1856- 1875
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
3	Unmanured	1635	219	529	35.1	30.9	33.0
4-1	Superphosphate ¹ ...	1671	149	673	35.7	31.5	33.6
8	Complex Min. Man. ²	2442	296	639	54.4	38.1	46.3
7	Complex Min. Man. ³	2579	806	573	55.2	56.0	55.6

¹ Mean of 4 Separations only, namely 1862, 1867, 1872, and 1875.

² Including potass 6 years, 1856-1861; without potass, 14 years 1862-1875.

³ Including potass 20 years, 1856-1875.

The quantities of nitrogen yielded are calculated from the results of actual determinations of the nitrogen in the mixed produce of the respective plots; but the estimates of the quantity of the produce referable to the different Natural Orders must be taken as only giving a general indication or an approximation to the truth; for, whilst the amount of the total mixed produce is the average of that of the twenty years, the amount of it referred to the different orders is calculated upon their percentage determined in six years only, four of which are among the last five, and the fluctuation according to season is in some cases very considerable, whilst in others there is a progression in the changes, which render an accurate estimate of the average botanical composition of the herbage over the whole period impossible. The figures do, however, undoubtedly represent the truth sufficiently nearly for our present purpose. But before referring to the yield of nitrogen, it may be remarked, in passing, how much greater is the increase of gramineous produce by the use of purely mineral manures in this mixed herbage than in the case of gramineous crops grown separately. The interesting question arises, how far the result is due to the direct action of the mineral manures in enabling the grasses to form much more stem and seed—that is, the better to mature—which, as a matter of fact, they are found to do? or how far the increased growth is to be explained by an increased accumulation of combined nitrogen available for the grasses in the upper layers of the soil, as the result of the increased growth of the leguminosæ induced by the potass manure, as already illustrated by the results obtained in alternating clover and barley, and in an actual course of rotation?

Referring to the yield of nitrogen, it is seen that, without manure, it has diminished during the last as compared with the first 10 years; but that the average is 33 lbs. per acre, per annum, or considerably more than with a gramineous crop grown separately.

With super-phosphate of lime alone, the yield of nitrogen over the first 10, the second 10, and the 20 years, is very nearly the same as without manure. It is slightly higher, as also is the total amount of produce; but whilst the quantity contributed by gramineous species is rather more, that yielded by leguminous species is less, and that by species belonging to other orders more than without manure.

With super-phosphate of lime, and sulphates of potass, soda, and magnesia, during the first 6 years, but no potass during the last 14 years (plot 8), the amount of both gramineous and leguminous herbage is very much increased; and that of the leguminous produce

was especially so during the earlier years. The result is a yield of 55·4 lbs. of nitrogen per acre, per annum, over the first 10 years, of only 38·1 lbs. over the second 10 years, and of 46·3 lbs. over the 20 years.

With the complex mineral manure, including potass each year throughout the period of twenty years (plot 7), leguminous species contribute about one-fifth of the whole produce, or very much more than in either of the other cases. The result is an annual yield of 55·2 lbs. of nitrogen over the first 10 years; of even slightly more, or 56 lbs., over the second 10 years; and of 55·6 lbs. over the whole period of 20 years—that is, considerably more than twice as much as would be yielded by a gramineous crop grown separately on arable land. It may here be observed that, whilst in the case of each of the first three plots referred to, the produce of the mixed herbage diminished over the second as compared with the first 10 years, that of plot 7, with the potass manure, and so much leguminous herbage, increased slightly over the second compared with the first 10 years. Finally, it may be remarked on this point, how comparatively uniform is the average yield of produce by all other species other than the gramineous and the leguminous on the four very differently manured plots.

Here again, then, the results relating to the growth of species of many different natural orders growing together, like those relating to the growth of individual species grown separately, show that those of the leguminous family, and probably those of various other orders also, have the capacity of assimilating much more nitrogen over a given area than species of the order graminæ.

Assuming for the sake of argument that the yield of nitrogen by the graminæ grown separately may be explained, as already suggested, by reference to the amount of combined nitrogen acquired from the measured aqueous deposits from the atmosphere, together with that condensed within the pores of the soil, and that derived from previous accumulations within it, the question arises, can the greatly increased yield by other plants be so accounted for? or, if not, how otherwise may it be explained? We will endeavour to weigh the evidence bearing upon this point.

It so happens that the plants which do gather, or which have been supposed to gather nitrogen more readily than the graminæ, have obviously a different character of foliage; as, for instance, the “root-crops”—turnips and the like; and the leguminous crops—beans, peas, clover, &c. An obvious explanation, therefore, which will be found in books of authority, is that these so distinguished “broad-leaved

plants" have the power of taking up nitrogen in some form from the atmosphere, in a degree, or in a manner, not possessed by the narrow-leaved gramineous plants. It is true that Adolph Mayer in Germany, and Schlösing in France, have experimentally shown that plants can take up nitrogen by their leaves from ammonia supplied to them in the ambient atmosphere. But I think I am right in saying that the conclusion of both of these experimenters is that this action takes place in a very immaterial degree in natural vegetation.

In reference to this subject, I may observe that the results of the determinations of the ammonia in the atmosphere by different experimenters, and in different localities, vary very greatly; and it may be concluded that a shower of rain will wash out much of it. According to M. Schlösing's statement of the results of his recent determinations of the ammonia in the air of Paris (*Compt. Rend.* lxxxi. p. 1252 et seq.), it ranges from one part in about 12, 500,000, to one part in about 260,000,000 of air by weight. If, for the purpose of illustration, we assume that, on the average, the ambient atmosphere in the open country—in Europe, at any rate—will contain one part of ammonia in about 60,000,000 of air, or one part of nitrogen as ammonia in about 50,000,000 of air, the atmosphere would thus contain more than 8000 times less nitrogen as ammonia than carbon as carbonic acid. But cereal crops contain 1 part of nitrogen to about 30 of carbon, and leguminous crops, 1 of nitrogen to 15, or fewer, of carbon. On these assumptions, the ambient atmosphere would contain a proportion of nitrogen as ammonia, to carbon as carbonic acid, about 267 times less than that of nitrogen to carbon in cereal produce, and about 534 times (or more) less than that in leguminous produce. It is true that water would absorb very much more nitrogen as ammonia, or dissolve very much more as carbonate or bi-carbonate of ammonia, than it would of carbon as carbonic acid under equal circumstances. Hence, there would appear to be a compensating quality for the small actual and relative amount of nitrogen as ammonia in the atmosphere, in the greater solubility or absorbability of the compounds in which nitrogen exists, than of the carbonic acid in which the carbon is presented. Further, it can hardly be to a greater mere extent of leaf or above-ground surface that the result could be attributed. Thus, though a bean and a wheat crop may yield about equal amounts of dry matter per acre, the bean produce would contain from two to three times more nitrogen, and approximate measurements show that a wheat plant offers a greater external superficies in relation to a given

weight of dry substance than a bean plant, and greater still therefore in relation to a given amount of nitrogen fixed. If, then, the bean can in some way take up more nitrogen from the atmosphere than the wheat, the result must be due to character and function, rather than to mere extent of surface above ground. It may, however, be observed that, as a rule, even those of the leguminous crops which are grown for their ripened seed, maintain their green and succulent surface, over a more extended period of the season of active growth, than do the gramineous corn crops.

It may safely be asserted, then, that neither direct experimental evidence, nor a consideration of the chemistry and the physics of the subject, would lead to the conclusion that the plants which assimilate more nitrogen over a given area than others, do so by virtue of a greater power of absorbing by their leaves combined nitrogen from the atmosphere in the form of ammonia. And here it may be said in passing that the argument would be still stronger against the supposition that nitric acid in the atmosphere supplies directly to the leaves of plants any important amount of the nitrogen they assimilate.

But apart from the more purely scientific considerations bearing upon the question, we believe that our statistics of nitrogen-production are themselves sufficient to justify the conclusion that, at any rate, the "broad-leaved" *root-crops*, turnips and the like, to which the function has with the most confidence been attributed, do not take up any important proportion of their nitrogen by their leaves from combined nitrogen in the atmosphere. Thus, it has already been shown, that the yield of nitrogen in these crops, even with the aid of complex mineral manures, was in the later years reduced to a lower point than that in any other crop; the percentage of nitrogen in the upper layers of the soil was also reduced to a lower point than with any other crop. The evidence of this kind is, however, admittedly not so conclusive in regard especially to plants of the leguminous family.

But as about four-fifths of the atmosphere which surrounds the leaves of plants consist of free nitrogen, why should not this be a source to them of the nitrogen they require? To assume that it is so, is such an obvious and easy way out of so many difficulties, that this assumption has from time to time been freely made, and much experimental investigation has been undertaken on the point with the most conflicting results. It is now nearly 40 years ago since Boussingault showed that there was a greater assimilation of nitrogen

over a given area in a rotation of crops than he could well account for; and almost from that time to this he has been occupied with investigations of very various kinds, sometimes on the atmosphere, sometimes on meteoric waters, sometimes on plants, and sometimes on soils, the main object of which has obviously been to throw light on the question of the sources of the nitrogen of vegetation. And almost for as long a period as Boussingault, Mr. Lawes and myself have devoted much thought and investigation to the same end.

On this point, of whether or not plants assimilate the free nitrogen of the atmosphere, leaving out of view, for lack of time and space, the experiments and conclusions of several others who have worked on the subject on a less comprehensive scale, I will first briefly direct attention to the most comprehensive series of experiments, the results of which led the author to conclude that the free nitrogen of the atmosphere is taken up and assimilated by the leaves of plants.

During the years 1849, 1850, 1851, 1852, 1854, 1855, and 1856, M. G. Ville, of Paris, made numerous experiments on this subject. His plants were generally enclosed in a glass case, and his soils consisted of washed and ignited sand, sand and brick, or sand and charcoal. They were sometimes supplied with a current of unwashed air, sometimes with a current of washed air, and they were sometimes in free air; sometimes a known quantity of ammonia was supplied to the air of the apparatus, and sometimes known quantities of nitrate were supplied to the soil. Lastly a great variety of plants was experimented upon. M. G. Ville's results are summarised in Table V. below.

TABLE V.

Summary of the Results of M. G. VILLE'S Experiments, to determine whether Plants assimilate free Nitrogen.

Plants.	Nitrogen—Grammes.			Nitrogen in Products to 1 Supplied.
	In Seed, and Air; and Manure, if any.	In Products.	Gain or Loss.	
1849: <i>Current of unwashed air supplying 0.001 grammes Nitrogen as Ammonia.</i> ¹				
Cress	0.0260	0.1470	0.1210	5.6
Large Lupins ...	0.0640	0.0640	0.0000	1.0
Small Lupins ...	0.0640	0.0470	—0.0170	0.7
	0.1550	0.2580	0.1030	1.7

¹ Recherches Expérimentales sur la Végétation, par M. GEORGES VILLE. Paris, 1853.

TABLE V.—*continued.*

Plants.	Nitrogen- Grammes.			Nitrogen in Products to 1 Supplied.
	In Seed, and Air ; and Manure, if any.	In Products.	Gain or Loss.	
1850 : <i>Current of unwashed air supplying 0'0017 grammes Nitrogen, as Ammonia.</i> ¹				
Colza (plants) ...	0'0260	1'0700	1'0440	41'1
Wheat	0'0160	0'0310	0'0150	1.9
Rye	0'0130	0'0370	0'0240	2'8
Maize	0'0290	0'1280	0'0990	4'4
	0'0857	1'2660	1'1803	14'8
1851 : <i>Current of washed air.</i> ¹				
Sunflower	0'0050	0'1570	0'1520	31'4
Tobacco	0'0040	0'1750	0'1710	43'7
Tobacco	0'0040	0'1620	0'1580	40'5
1852 : <i>Current of washed air.</i> ¹				
Autumn Colza ...	0'0480	0'2260	0'1780	4'7
Spring Wheat ...	0'0290	0'0650	0'0360	2'2
Sunflower	0'0160	0'4080	0'3920	25'5
Summer Colza ...	0'1730	0'5950	0'4220	3'4
Summer Colza ...	0'1050	0'7010	0'5960	6'7
1854 : <i>Current of washed air (under superintendence of a Commission).</i>				
Cress... ..	0'0099	0'0097	—0'0002	1'0
Cress... ..	0'0038	0'0530	0'0492	13'9
Cress... ..	0'0039	0'0110	0'0071	2'8
1854 : <i>Current of washed air (closed, under superintendence of a Commission.</i> ²				
Cress... ..	0'0063	0'0350	0'0287	5'6
1855 and 1856 : <i>In free air, with 0'5 grammes Nitre = 0'069 Nitrogen.</i> ³				
Colza	0'0700	0'0700 ⁴	0'0000	1'0
Colza	0'0700	0'0660 ⁴	—0'0040	0'9
Colza	0'0700	0'0680 ⁴	—0'0020	1'0
1855 and 1856 : <i>In free air, with 1 gramme Nitre = 0'138 Nitrogen.</i> ³				
Colza	0'1400	0'1970 ⁴	0'0570	1'41
Colza	0'1400	0'3740 ⁴	0'2340	2'67
Colza	0'1400	0'2160 ⁴	0'0760	1'54
Colza	0'1400	0'2500 ⁴	0'1100	1'79

¹ Recherches Expérimentales sur la Végétation, par M. GEORGES VILLE. Paris, 1853.² Compt. rend., 1855. ³ Recherches Expérimentales sur la Végétation, 1857. ⁴ In Plants only.

TABLE V.—*continued.*

Plants.	Nitrogen—Grammes.			Nitrogen in Products to Supplied.
	In Seed, and Air ; and Manure, if any.	In Products.	Gain or Loss.	
1856 : <i>In free air, with 0.792 grammes Nitre = 0.110 Nitrogen.</i> ¹				
Wheat	0.1260	0.2180 ²	0.0920	1.7
Wheat	0.1260	0.2240 ²	0.0980	1.8
1855 : <i>In free air, with 1.72 grammes Nitre = 0.238 Nitrogen.</i> ¹				
Wheat	0.2590	0.3080 ²	0.0490	1.2
1856 : <i>In free air, with 1.765 grammes Nitre = 0.244 Nitrogen.</i> ¹				
Wheat	0.2650	0.2170 ²	—0.0480	0.8
Wheat	0.2650	0.3500 ²	+0.0850	1.3

We have already discussed the results of M. G. Ville, as well as those of others, in a paper published in the *Philosophical Transactions* for 1859, and in a somewhat condensed form in the *Journal of the Chemical Society*, Vol. xvi. 1863; and we can only very briefly refer to them in this place. The column of actual gain or loss of nitrogen is seen to show in one case a gain of more than 1 gram of nitrogen; the amount of it in the products being more than 41 fold that supplied as combined nitrogen in the seed, and air. This result was obtained with colza. Those obtained with wheat, rye, or maize, showed very much less of both actual and proportional gain. Experiments with sunflower and tobacco showed a less actual gain than that with colza; but still it amounted in one case, with sunflower, to more than 30, and in two, with tobacco, to more than 40 fold of that supplied. In M. G. Ville's later experiments (as a glance down the last two columns in the Table will show), although he still had generally some gain, it was usually both actually and in proportion to the quantity supplied considerably less than in his earlier ones.

M. G. Ville attributed the gain, in some cases, to the large leaf-surface. In explanation of the assimilation of free nitrogen by plants, he calls attention to the fact that nascent hydrogen is said to give ammonia, and nascent oxygen nitric acid, with free nitrogen, and he asks—Why should not the nitrogen in the juices of the plant

¹ Recherches Expérimentales sur la Végétation, 1857. ² In Plants only.

combine with the nascent carbon and oxygen in the leaves? He refers to the supposition of M. De Luca, that the nitrogen of the air combines with the nascent oxygen given off by the leaves of plants, and to the fact that the juice of some plants (mushrooms) has been observed to ozonize the oxygen of the air, and he asks—Is it not probable, then, that the nitrogen dissolved in the juices will submit to the action of the ozonized oxygen with which it is mixed, when we bear in mind that the juices contain alkalies, and penetrate tissues, the porosity of which exceeds that of spongy platinum?

The experiments of M. Boussingault, and of ourselves, on the other hand, have not given an affirmative answer to the question whether plants, by their leaves, take up and assimilate the free nitrogen of the air.

M. Boussingault commenced his experiments on this subject in 1837, and Table VI., which follows, summarises his results, obtained at intervals from that date up to 1858.

TABLE VI.

Summary of the Results of M. BOUSSINGAULTS' Experiments, to determine whether Plants assimilate free Nitrogen.

Plants.	Nitrogen- Grammes.			Nitrogen in Products to 1 Supplied.
	In Seed, or Plants; and Manure, if any.	In Products.	Gain or Loss.	
1837: <i>Burnt soil, distilled water, free air, in closed summer-house.</i> ¹				
Trefoil... ..	0'1100	0'1200	+0'0100	1'09
Trefoil... ..	0'1140	0.1560	+0'0420	1'37
Wheat... ..	0'0430	0'0400	—0'0030	0'93
Wheat... ..	0'0570	0'0600	+0'0030	1'05
1838: <i>Conditions as in 1837.</i> ²				
Peas	0'0460	0'1010	+0'0550	2'20
Trefoil (Plants)	0'0330	0'0560	+0'0230	1'70
Oats (Plants)	0'0590	0'0530	—0'0060	0'90
1851 and '52: <i>Washed and ignited pumice with ashes, distilled water limited air, under glass shade, with Carbonic Acid.</i> ³				
Haricot, 1851	0'0349	0.0340	—0'0009	0'97
Oats, 1851	0'0078	0'0067	—0'0011	0'86
Haricot, 1852	0'0210	0'0189	—0'0021	0'90
Haricot, 1852	0'0245	0'0226	—0'0019	0'92
Oats, 1852	0'0031	0'0030	—0'0001	0'97

¹ Ann. Ch. Phys., [2] lxxvii, (1838). ² Ibid, lxi. ³ Ann. Ch. Phys. [3] xli. (1854).

TABLE VI.—*continued.*

Plants.	Nitrogen—Grammes.			Nitrogen in Products to 1 Supplied.
	In Seed, or Plants; and Manure, if any.	In Products.	Gain or Loss.	
1853: Prepared pumice, or burnt brick, with ashes; distilled water, limited air, in glass globe, with Carbonic Acid. ³				
White Lupin	0'0480	0'0483	+0'0003	1'01
White Lupin	0'1282	0'1246	—0'0036	0'97
White Lupin	0'0349	0'0339	—0'0010	0'97
White Lupin	0'0200	0'0204	+0'0004	1'02
White Lupin	0'0399	0'0397	—0'0002	1'00
Dwarf Haricot	0'0354	0'0360	+0'0006	1'02
Dwarf Haricot	0'0298	0'0277	—0'0021	0'93
Garden Cress	0'0013	0'0013	0'0000	1'00
White Lupin	0'1827	0'1697	—0'0130	0'93
1854: Prepared pumice with ashes, distilled water, current of washed air, and Carbonic Acid, in glazed case. ⁴				
Lupin	0'0196	0'0187	—0'0009	0'95
Dwarf Haricot	0'0322	0'0325	+0'0003	1'01
Dwarf Haricot	0'0335	0'0341	+0'0006	1'02
Dwarf Haricot	0'0339	0'0329	—0'0010	0'97
Dwarf Haricot	0'0676	0'0666	—0'0010	0'99
Lupin	0'0180	0'0334	—0'0021	0'94
Lupin	0'0175			
Cress	0'0046	0'0052	+0'0006	1'13
1851, '52, '53, and 54: Prepared soil, or pumice with ashes; distilled water, free air, under glazed case. ⁴				
Haricot (dwarf), 1851	0'0349	0'0380	+0'0031	1'09
Haricot, 1852	0'0213	0'0238	+0'0025	1'12
Haricot, 1853	0'0293	0'0270	—0'0023	0'92
Haricot (dwarf), 1854	0'0318	0'0350	+0'0032	1'10
Lupin (white), 1853 ...	0'0214	0'0256	+0'0042	1'20
Lupin 1854... ..	0'0199	0'0229	+0'0030	1'15
Lupin 1854... ..	0'0367	0'0387	+0'0020	1'05
Oats, 1852... ..	0'0031	0'0041	+0'0010	1'32
Wheat, 1853	0'0064	0'0075	+0'0011	1'17
Garden Cress, 1854 ...	0'0259	0'0272	+0'0013	1'05
1858: Nitrate of Potassium as Manure. ⁵				
Helianthus	{ 0'0144 ⁶ 0'0255 ⁶	0'0130 0'0245	—0'0014 —0'0010	0'90 0'96

¹ Ann. Ch. Phys., [2] lxvii, (1838). ² Ibid, lxix. ³ Ann. Ch. Phys., [3] xli, (1854).
⁴ Ann. Ch. Phys., Sér. [3] xliii, (1855). ⁵ Compt. rend., xlvii, (1858). ⁶ Nitrogen in Seed and Nitrate.

M. Boussingault's soils consisted of burnt soil, washed and ignited pumice, or burnt brick ; his experiments were sometimes in free air, sometimes in a closed vessel with limited air, sometimes with a current of washed air, and sometimes in free air, but under a glass case. When the plants were enclosed, a supply of carbonic acid was provided, and in a few cases known quantities of nitre were supplied as manure.

The last two columns of the Table (VI.) show the actual and proportional gain of nitrogen in M. Boussingault's experiments. It will be observed that in his earliest experiments, those in free air, in a summer house, the leguminous plants, trefoil and peas, did indicate a notable gain of nitrogen ; but in all his subsequent experiments there was generally either a slight loss, or, if a gain, it was represented in only fractions, or low units, of milligrams. After twenty years of varied and laborious investigation of the subject, M. Boussingault concluded that plants have not the power of taking up and assimilating the free nitrogen of the atmosphere.

Our own experiments on this subject were commenced in 1857, and the late Dr. Pugh, of the Pennsylvania State Agricultural College, devoted between two and three years to the investigation at Rothamsted. Mr. Lawes has contributed one complete set of the apparatus employed to this exhibition. The arrangement, and the results obtained up to that date, are fully described in the papers already referred to, published in the *Philosophical Transactions* for 1859, and in the *Journal of the Chemical Society* in 1863. They may be briefly described as follows :—

The soils used were ignited, washed, and re-ignited, pumice, or soil. The specially made pots were ignited before use, and cooled over sulphuric acid under cover. The pots, with their plants, were enclosed under a glass shade resting in the groove of a specially made hard-baked glazed stone-ware lute-vessel, mercury being the luting material. Under the shade, through the mercury, passed one tube for the admission of air, another for its exit, and another for the supply of water or solutions to the soil ; and there was an outlet at the bottom of the lute-vessel for the escape of the condensed water into a bottle affixed for that purpose, from which it could be removed and returned to the soil at pleasure. A stream of water being allowed to flow into a large stone-ware Wolff's bottle (otherwise empty), air passed from it through two small glass Wolff's bottles containing sulphuric acid, then through a long tube filled with fragments of pumice saturated with sulphuric acid, and lastly through a Wolff's bottle containing a saturated solution of ignited carbonate of soda ; and,

after being so washed, the air enters the glass shade, from which it passes, by the exit tube, through an eight bulbed apparatus containing sulphuric acid, by which communication with the unwashed external air is prevented. Carbonic acid is supplied as occasion may require, by adding a measured quantity of hydrochloric acid to a bottle containing fragments of marble, the evolved gas being passed through one of the bottles of sulphuric acid, through the long tube, and through the carbonate of soda solution, before entering the shade.

It will be observed that, by the arrangement described, the washed air is forced, not aspirated, through the shade, and the pressure being thus the greater within the vessel, the danger of leakage of unwashed air from without inwards is lessened. In 1857, twelve sets of such apparatus were employed; in 1858 a larger number, some with larger lute-vessels, and shades; in 1859 six, and in 1860 also six. The whole were arranged, side by side, in the open air, on stands of brick-work, as described in the papers referred to, and shown in the apparatus exhibited. Drawings of some of the plants grown were also exhibited, and the published results are summarised in Table VII.

TABLE VII.

Summary of the Results of Experiments made at Rothamsted, to determine whether Plants assimilate Free Nitrogen.

			Nitrogen—Grammes.			Nitrogen in Products to 1 Supplied.	
			In Seed, and Manure if any.	In Plants, Pot and Soil.	Gain or Loss.		
<i>With NO combined Nitrogen supplied beyond that in the seed sown.</i>							
Gramineæ . .	1857. {	Wheat .	0'0080	0'0072	—0'0008	0'90	
		Barley .	0'0056	0'0072	+0'0016	1'11	
		Barley .	0'0056	0'0082	+0'0026	1'46	
	1858. {	Wheat .	0'0078	0'0081	+0'0003	1'04	
		Barley .	0'0057	0'0058	+0'0001	1'02	
		Oats . .	0'0063	0'0056	—0'0007	0'89	
	1858. { A ¹	Wheat .	0'0078	0'0078	0'0000	1'00	
		Oats . .	0'0064	0'0063½	—0'0001	0'98	
	Leguminosæ.	1857. {	Beans .	0'0796	0'0791	—0'0005	0'99
			Beans .	0'0750	0'0757	+0'0007	1'01
			Peas . .	0'0188	0'0167	—0'0021	0'89
	Other Plants.	1858. {	Buck Wheat.	0'0200	0'0182	—0'0018	0'91

¹ These experiments were conducted in the apparatus of M. G. Ville.

TABLE VII.—*continued.*

		Nitrogen—Grammes.			Nitrogen in Products to 1 Supplied.	
		In Seed, and Manure if any.	In Plants, Pot and Soil.	Gain or Loss.		
<i>WITH combined Nitrogen supplied beyond that in the seed sown.</i>						
Gramineæ . .	1857.	{ Wheat .	0'0329	0'0383	+0'0054	1'16
		{ Wheat .	0'0329	0'0331	+0'0002	1'01
		{ Barley .	0'0326	0'0328	+0'0002	1'01
		{ Barley .	0'0268	0'0337	+0'0069	1'25
	1858.	{ Wheat .	0'0548	0'0536	—0'0012	0'98
		{ Barley .	0'0496	0'0464	—0'0032	0'94
		{ Oats . .	0'0312	0'0216	—0'0096	0'69
	1858. A ¹	{ Wheat .	0'0268	0'0274	+0'0006	1'02
		{ Barley .	0'0257	0'0242	—0'0015	0'94
		{ Oats . .	0'0260	0'0198	—0'0062	0'76
Leguminosæ.	1858.	{ Peas . .	0'0227	0'0211	—0'0016	0'93
		{ Clover .	0'0712	0'0665	—0'0047	0'93
	1858. A ¹	{ Beans . .	0'0711	0'0655	—0'0056	0'92
Other Plants.	1858.	{ Buck Wheat. }	0'0308	0'0292	—0'0016	0'95

The upper part of the Table shows the results obtained in 1857 and 1858 in the experiments in which no combined nitrogen was supplied beyond that contained in the seed sown. The drawings show how extremely restricted was the growth under these conditions, and the figures in the Table show that neither with the gramineæ, the leguminosæ, nor with buckwheat, was there in any case a gain of three milligrams of nitrogen indicated. In most cases there was much less gain than this, or a slight loss. There was in fact nothing in these results to lead to the conclusion that either the gramineæ, the leguminosæ, or the buckwheat had assimilated free nitrogen.

The lower part of the Table shows the results obtained in 1857 and 1858, in the experiments in which the plants were supplied with known quantities of combined nitrogen in the form of a solution of ammonium sulphate applied to the soil. The gains or losses range a little higher

¹ These experiments were conducted in the apparatus of M. G. Ville.

in these experiments, in which larger quantities of nitrogen were involved, but they are always represented by units of milligrams only, and the losses are higher than the gains. Further, the gains, such as they are, are all in the experiments with the gramineæ, whilst there is in each case a loss with the leguminosæ, and with the buckwheat. On this point it should be stated that the growth was far more healthy with the gramineæ than with the leguminosæ, which are even in the open fields very susceptible to the vicissitudes of heat and moisture, and were found to be extremely so when enclosed under glass shades. It might be objected, therefore, that the negative results with the leguminosæ are not so conclusive as those with the gramineæ. However this may be, taking the results as they stand, there is nothing whatever in them to lead to the conclusion that either the gramineæ or the leguminosæ can take up and assimilate the free nitrogen of the atmosphere. We, indeed, do not hesitate to conclude from our own experiments, as Boussingault did from his, that the evidence is strongly against the supposition that plants can so avail themselves of the free nitrogen of the atmosphere.

Independently of the action suggested as possible by M. G. Ville, that is between free nitrogen and nascent or ozonized oxygen within the plant itself, it has been supposed that the free nitrogen of the atmosphere may unite with the nascent oxygen, or ozone, as the case may be, evolved by the plant, and so yield nitric acid. In our papers above referred to we have given reasons for supposing that such actions are not likely to take place; but whether they do or do not, it is at any rate certain that in our own experiments we have not been able to persuade plants to avail themselves of this happy faculty of producing their own nitrogenous food. With regard to the action supposed possibly to take place externally to the plant itself, if it were in any material degree operative, we should expect some, at least, of the resulting combined nitrogen to be collected in the aqueous deposits from the atmosphere; but we have seen how inadequate is the amount of combined nitrogen in those deposits to account for the yield of nitrogen, even of the gramineæ, and still less can it satisfactorily explain the yield in the leguminosæ and other plants.

But if the plant itself cannot either assimilate free nitrogen, or effect its combination so as to bring it into a state for its use, may not such combination take place under the influence of the soil?

More than 30 years ago, Mulder argued that in the last stages of decomposition of organic matter in the soil, hydrogen was evolved,

and that this nascent hydrogen combined with the free nitrogen of the air, and so formed ammonia.

A few years ago Dehérain substantially revived this view. He maintained that at a certain depth the air of the soil is poor in, or destitute of, oxygen; that hydrogen is evolved from the decomposing organic matter; that it unites with free nitrogen to form ammonia; and, that so, combined nitrogen increases in the soil in spite of the growth and removal of crops. This view he supports by some laboratory experiments.

It is obvious that if the reality of this action in soils were unquestionably established, it would greatly aid the solution of the question we are discussing. There are, indeed, results of others on record which would seem to lend it probability.

Thus, Bretschneider found, on exposure of a mixture of humic acid and quartz sand to the air for a whole year, under conditions in which it was protected from rain and insects, that there was a gain of combined nitrogen which would represent an increase of more than 40 lbs. per acre.

Again, Boussingault exposed a moist garden soil for three months, and found a small gain of nitrogen. His explanation, was, however, different. He supposed it possible that ozone might be evolved in the oxydation of organic matter in the soil, and unite with free nitrogen, and so nitric acid be produced, and the soil gain in combined nitrogen. In other experiments Boussingault put mixtures of vegetable mould and pure sand in small quantities in large glass vessels which he perfectly closed and preserved in a dark cellar for a whole year. At the end of that period oxydation of organic matter had taken place, nitric acid was formed, but there was upon the whole a small loss of combined nitrogen. Lastly in regard to Boussingault's results bearing upon this point, it has already been shown that in all of his experiments with plants in which his soils consisted of ignited pumice, ignited brick, or the like, without organic matter, he found no gain of combined nitrogen in soil and plant. In 1858 and 1859, however, he made a number of experiments on growth, in which part of the soil consisted of rich garden mould; and in two cases with lupins growing in confined air, and in one with haricot growing in free air, his results showed a notable gain of combined nitrogen; and although the quantity of garden mould employed was not the same in the three cases, the gain of nitrogen was approximately in proportion to the amount of soil used. The gain was, indeed, in the soil rather than in the plant.

In the other experiments, however, either much less, or no gain was indicated.

Much more recently, Boussingault has published the results of experiments which showed that when a garden soil was confined for about 11 years in closed glass vessels in an atmosphere containing oxygen, the free nitrogen did not serve for the formation of nitric acid within it; but, on the contrary, the soil lost a portion of its combined nitrogen.

Since the delivery of this lecture, M. Berthelot (*Compt. Rend.*, T. lxxxii. p. 1,357) has stated that in experiments in which he exposed moistened cellulose to an electric current in an atmosphere of nitrogen, he found nitrogen taken up, and a fixed nitrogenous body formed. Referring to the last mentioned experiments of M. Boussingault, and his conclusions from them, M. Berthelot objects that the soils being in closed glass vessels, the intervention of atmospheric electricity was excluded, and the conditions of the experiments were, so far, unlike those of a natural soil.

Being very desirous to know the present opinion of M. Boussingault on the various points involved in this important question of the sources of the nitrogen of vegetation, I wrote to him shortly after undertaking to give this address, and asked whether he would be kind enough to favour me with a statement of his views on certain points. Unfortunately his reply did not reach me until after the delivery of the lecture; but, with his permission, I am now enabled to contribute a very valuable addition to the discussion in the form of a translation of the more essential parts of M. Boussingault's letter. He says :—

“(1.) In confined stagnant air, or in air moving through a closed apparatus, after previous purification, but still containing carbonic acid, plants growing in a soil destitute of nitrogenous manure, but containing the mineral substances indispensable for the vegetable organism, do not assimilate the nitrogen which is in a gaseous state in the atmosphere.”

“(2.) In the open air, in a soil destitute of nitrogenous manure, but containing the mineral substances necessary for the vegetable organism, plants acquire very minute quantities of nitrogen, arising, no doubt, from minute proportions of fertilising nitrogenous ingredients carried by the air, ammoniacal vapours, and dust, always containing alkalien or earthy nitrates.”

“(3.) In confined stagnant air, or in air renewed in a closed apparatus, a plant growing in a soil containing a nitrogenous manure, and

mineral substances necessary for the vegetable organism, or in fertile vegetable earth, does not assimilate free nitrogen."

"(4.) In field culture, where dung is applied in ordinary quantities, analysis shows that there is more nitrogen in the crops than was contained in the manure applied."

"This excess of nitrogen comes from the atmosphere, and from the soil."

"(A.) From the atmosphere, because it furnishes ammonia in the form of carbonate, nitrates or nitrites, and various kinds of dust. Theodore de Saussure was the first to demonstrate the presence of ammonia in the air, and consequently in meteoric waters. Liebig exaggerated the influence of this ammonia on vegetation, since he went so far as to deny the utility of the nitrogen which forms a part of farm-yard manure. This influence is, nevertheless, real, and comprised within limits, which have quite recently been indicated in the remarkable investigations of M. Schlösing."

"(B.) From the soil, which, besides furnishing the crops with mineral alkaline substances, provides them with nitrogen, by ammonia, and by nitrates, which are formed in the soil at the expense of the nitrogenous matters contained in diluvium, which is the basis of vegetable earth; compounds in which nitrogen exists in stable combination, only becoming fertilising by the effect of time. If we take into account their immensity, the deposits of the last geological periods must be considered as an inexhaustible reserve of fertilising agents. Forests, prairies, and some vineyards, have really no other manures than what are furnished by the atmosphere, and by the soil. Since the basis of all cultivated land contains materials capable of giving rise to nitrogenous combinations, and to mineral substances, assimilable by plants, it is not necessary to suppose that in a system of cultivation the excess of nitrogen found in the crops is derived from the free nitrogen of the atmosphere. As for the absorption of the gaseous nitrogen of the air by vegetable earth, I am not acquainted with a single irreproachable observation that establishes it; not only does the earth not absorb gaseous nitrogen, but it gives it off, as you have observed in conjunction with Mr. Lawes, as Reiset has shown in the case of dung, as M. Schlösing and I have proved in our researches on nitrification."

"If there is one fact perfectly demonstrated in physiology, it is this of the non-assimilation of free nitrogen by plants; and I may add by plants of an inferior order, such as mycodermis, and mushrooms."

✓ Numerous experiments of Schlösing indicate a similar result to that last quoted of Boussingault. He selected a soil rich in humus, containing about 16 per cent. of moisture, and 0.263 per cent of combined nitrogen. Known quantities of it were placed in large wide glass tubes, and during a period of about four months, he aspirated over them air containing respectively from 1.5 to 21 per cent. of oxygen. He determined the carbonic acid in the air passing off, and the nitric acid in the soil before and after the experiment. He found that both the combustion of the organic matter, and the formation of nitric acid, were very considerable, even with the lowest proportion of oxygen in the air; but that the formation of the nitric acid in particular was very much the greater, the larger the proportion of oxygen in the air.

In a second set of experiments, he used the soil in a moister condition; and instead of the experiment in which the air contained only 1.5 of oxygen, he employed pure nitrogen; and the experiments extended over a period of about six months. In the case in which the aspirated air contained no oxygen, the whole of the nitric acid previously existing in the soil disappeared; but in the other cases there was a considerable formation of nitric acid.

In a third set of experiments, Schlösing determined the nitric acid in the soils, and added known quantities of potassium nitrate in a dilute solution. The mixture was enclosed in a flask of several times the capacity of the volume of soil. At the conclusion of the experiment only traces, if any, of gas containing hydrogen and carbon were present in the air of the vessel. The amount of ammonia in the soil increased considerably, but in only small proportion to that which the nitric acid would yield. At the end of the first experiment more potassium nitrate was added, and an atmosphere of known volume and composition supplied. At the conclusion of this experiment the soil contained no nitric acid; the amount of ammonia was increased, but again in only small proportion to the amount which the nitrate would yield. There was indeed a loss of total nitrogen in the soil.

Schlösing concludes that the combustion of organic matter in the soil is accompanied by a loss of nitrogen; that the combustion may be at the cost of the air as in the experiment of Boussingault, or at the cost of nitrates, of ferric oxide, or of the oxygen of the organic matter, as in his own experiments.

It will be seen that on this important point of whether or not the soil

may acquire combined nitrogen either in the form of ammonia by the combination of free nitrogen with nascent hydrogen evolved in the decomposition of organic matter in defect of oxygen, or in the form of nitric acid by the oxydation of free nitrogen, the evidence is, to say the least, conflicting. The more recent results of Boussingault, and those of Schlösing, would, however, indicate a greater probability of a loss of combined nitrogen, and evolution of free nitrogen.

Judging of the probabilities by reference to some of the results of our own investigations, we think that they are rather against than in favour of the supposition that there is any material gain of the kind assumed by Mulder and Dehérain. It may be well, however, briefly to call attention to some few facts which seem to bear upon the point, whether in favour, or otherwise, of the view in question.

The action assumed by Mulder and Dehérain, if it have place at all in soils in their natural condition, would be supposed, and is assumed by Dehérain, to occur in layers sufficiently deep to be poor in oxygen. In the lower layers of the soil there is, however, a deficiency of carbonaceous organic matter also. Again, if such formation of ammonia do take place, it is probable that some at any rate of it must be oxidated into nitric acid; a condition which, on the other hand, implies an atmosphere not poor in oxygen. Thus, numerous results of analysis of the drainage water from many of the experimental plots at Rothamsted, to which further reference will be made presently, show that nearly the whole of the combined nitrogen in the drainage collected at a depth of about 30 inches, exists as nitrates and nitrites; which, obviously, would hardly be the case if the solution passed through a considerable layer of soil, the interstices of which contained an atmosphere poor in, or destitute of, oxygen.

Again, assuming such formation of ammonia to take place in the upper layers of the soil, where there is the most organic matter, and much oxidation of it, the supposition would be that the conditions would favour oxidation rather than the formation of ammonia from free nitrogen; and the fact of the formation of a good deal of nitric acid by the oxidation of nitrogenous organic matter, or ammonia, in the surface soil, is sufficiently established.

Further, if it were to the action assumed by Mulder and Dehérain taking place in the upper layers of the soil that we owe the supplies of combined nitrogen available to leguminous and other plants which assimilate so much more of it over a given area than the gramineæ, the question may be asked—why cannot the gramineæ avail themselves

of this superficial supply? On this point it may be mentioned that, on some parts of the experimental wheat and barley fields at Rothamsted, farm-yard manure has been applied year after year, for a quarter of a century or more, in quantity containing perhaps six or seven times as much nitrogen as is removed in the increase of crop, and that thus the percentage of nitrogen in the surface soil has been more than doubled. Yet, as large a produce of barley, and a larger produce of wheat, is annually obtained by the use of very much smaller quantities of nitrogen, as ammonia-salts or nitrate. It would thus appear that the nitrogen of the farm-yard manure was only available to the cereals after its transformation into ammonia or nitric acid. Unfortunately, we are not at present able to adduce direct experimental evidence as to the condition in which the large amount of inefficient nitrogen exists in the soil, or as to whether a leguminous crop would or would not grow luxuriantly in it, but there is little doubt that it would do so. On the other hand, a good crop of clover would appear to be attainable in soil comparatively poor in nitrogen in its upper layers, and comparatively poor in organic matter also; for, in the experiments already referred to in which barley was grown after barley and after clover, the large amount of clover obtained, and nitrogen assimilated in it, was after six corn crops grown by artificial manure alone; conditions under which the amount, both of available nitrogen, and of organic matter, in the upper layers of the soil, would be supposed to be comparatively small.

The answer of Dehérain would probably be, that under the circumstances supposed, the nitrogen would be in a condition of combination not favourable for assimilation by the gramineæ; that, in fact, the ammonia formed would combine with organic acids in the soil, yielding compounds specially favourable as food for the leguminosæ. An objection to this view is, that if the accumulation in the soil by time, of nitrogen in a condition specially favourable for the leguminosæ were such as is here assumed, we should expect the amount of nitrogen in the soil, determinable by the soda-lime process, to be higher before than after the growth of a leguminous crop; whereas, on the contrary, after the growth of a leguminous crop, the amount of nitrogen so determinable in the upper layers of the soil is very appreciably increased.

The evidence in favour of the supposition that the special source of nitrogen to the leguminosæ is ammonia, or other compounds than nitric acid, in the upper layers of the soil, is then, to say the least, inconclusive

It remains to consider whether it may not be nitric acid, either in the soil or in the subsoil?

As already said, there is abundant evidence of the formation and existence of a considerable amount of nitric acid in surface soils; even in such as contain a relatively high amount of carbonaceous and nitrogenous organic matter. For example, a soil at Rothamsted which has been under garden cultivation, and as such probably manured almost every year for centuries, has successfully grown clover every year for more than twenty years. This soil was shown by the late Dr. Pugh, and has been again recently by Mr. Warrington, to contain a considerable amount of nitric acid. But such a soil would, there is no doubt, grow large crops of gramineæ also; which direct experiments show to attain great luxuriance under the influence of artificially applied nitrates. But such a rich garden soil contains an abundance of every thing—mineral constituents, carbonaceous organic matter, and combined nitrogen in various forms, and thus the exact conditions which it supplies favourable to the leguminosæ cannot at once be discriminated. The fact of the comparatively little, or at least uncertain, action of directly applied nitrates on the growth of the leguminosæ, would seem to be inconsistent with the supposition that it is the nitric acid in such a surface soil that has given it its special adaptation for the growth of clover for so many years—unless, indeed, it be the case, that it is much more available to such crops when in combination with some bases than with others.

The next point to consider is, whether there are any facts in favour of the supposition that clover, and leguminous crops generally, acquire any material proportion of their nitrogen in lower layers, and in a more extended range of the soil, than the gramineæ. As an element in the discussion of this question it will be well in the first place to call attention to the effects of direct nitrogenous manures, such as ammonia-salt, or nitrates, on the growth of some of our crops.

In Table VIII. is shown the estimated amounts of carbon, yielded per acre per annum, in wheat over twenty years, in barley over twenty years, in sugar-beet over three years, and in beans over eight years; each with a complex mineral manure alone, and each with the same mineral manure and given quantities of nitrogen in addition, supplied in some cases in the form of ammonia-salts, and in others as nitrate. The gain of carbon by the use of the nitrogenous manure is also given.

TABLE VIII.

Estimated yield and gain of Carbon per acre, per annum, in experimental Crops at Rothamsted.

Manuring, Quantities per acre, per annum.	Average Carbon per acre, per annum.	
	Actual	Gain.
<i>Wheat 20 years, 1852-1871.</i>		
	lbs.	lbs.
Complex Mineral Manure	988	
Complex Min. Man. & 41 lbs. Nitrogen, as Ammonia...	1590	602
Complex Min. Man. & 82 lbs. Nitrogen, as Ammonia...	2222	1234
Complex Min. Man. & 82 lbs. Nitrogen, as Nitrate ...	2500	1512
<i>Barley 20 years, 1852-1871.</i>		
Complex Mineral Manure	1138	
Complex Min. Man. & 41 lbs. Nitrogen, as Ammonia...	2088	1150
<i>Sugar-Beet 3 years, 1871-1873.</i>		
Complex Mineral Manure	1136	
Complex Min. Man. & 82 lbs. Nitrogen, as Ammonia...	2634	1498
Complex Min. Man. & 82 lbs. Nitrogen, as Nitrate ...	3081	1945
<i>Beans 8 years, 1862 and 1864-1870.</i>		
Complex Mineral Manure	726	
Complex Min. Man. & 82 lbs. Nitrogen, as Nitrate ...	992	266

It is quite evident that in the case of the gramineous crops, wheat and barley, which contain a comparatively low percentage of nitrogen, and assimilate a comparatively small amount of it over a given area, and also in that of the sugar-beet, there was a greatly increased amount of carbon assimilated by the addition of nitrogenous manure alone. In the case of the wheat, there is much more effect from a given amount of nitrogen supplied as nitrate, which is always applied in the spring, than from an equal quantity as ammonia-salts, which are applied in the autumn, and are subject to winter drainage. There is also more effect from ammonia-salts applied to barley than to wheat; the application being made for the former in the spring and for the latter in the autumn. There is again more effect from the nitrate than from the ammonia-salts when applied to sugar-beet, the application being made in both cases at the same date, in the spring.

On the other hand, the effect of the nitrogenous manure upon the highly nitrogenous bean crop is seen to be, comparatively, very insignificant.

In reference to this point it should be observed that there has been

this greatly increased assimilation of carbon in the wheat and in the barley for more than twenty years, without the addition of any carbon to the soil. It is indeed certain that, in the existing condition of our soils, the increased growth of our staple starch-yielding grains is greatly dependent on a supply of nitrogen to the soil. It is equally certain that the increased production of sugar in the gramineous sugar-cane, in the tropics, is likewise greatly dependent on the supply of nitrogen to the soil.

In reference to the great increase in the assimilation of carbon in the sugar-beet by the use of purely nitrogenous manures, it may be of interest to observe that over the three years of the experiments with sugar-beet, the increased production of sugar per acre per annum was about 20 cwts. by the use of 82 lbs. of nitrogen per acre per annum as ammonia-salts, and about 28 cwts. by the use of 82 lbs. of nitrogen as nitrate of soda.

It is then our characteristically starch and sugar producing crops that are the most characteristically benefited by the application of nitrogenous manures; whilst our highly nitrogenous leguminous crops are comparatively little benefited by such manures.

But now let us consider what is the proportion of the nitrogen supplied in manure that we get back in the increase of the crops that are the most specially benefited by its use?

In Table IX. is shown the amount of nitrogen recovered, and the amount not recovered, in the increase of crop for 100 supplied in manure, to wheat, and to barley, respectively; the result being in each case the average over a period of twenty years.

TABLE IX.

Nitrogen recovered, and not recovered, in the increase of produce, for 100 supplied in Manure.

Manuring, Quantities per acre, per annum.	For 100 Nitrogen in Manure.	
	Reco- vered in Increase.	Not Re- covered in Increase.
<i>Wheat 20 years, 1852-1871.</i>		
Complex Min. Man. & 41 lbs. Nitrogen, as Ammonia...	32'4	67'6
Complex Min. Man. & 82 lbs. Nitrogen, as Ammonia...	32'9	67'1
Complex Min. Man. & 82 lbs. Nitrogen, as Nitrate ...	45'3	54'7
<i>Barley 20 years, 1852-1871.</i>		
Complex Min. Man. & 41 lbs. Nitrogen, as Ammonia...	48'1	51'9

Speaking generally, it may be said that, notwithstanding the great effects produced by the nitrogenous manures, two-thirds of the nitrogen supplied were unrecovered in the increase of crop when the ammonia-salts were applied to wheat ; the application being made in the autumn. When, however, nitrate of soda was used, which is always applied in the spring, the quantity left unrecovered was not much more than half that supplied. With barley also, the manuring for which takes place in the spring, there is again nearly half the nitrogen supplied in the manure recovered in the increase, and therefore little more than half left unrecovered.

It may be observed that, in the case of root-crops, when the supply of nitrogen is not excessive, the proportion of the nitrogen of the manure recovered in the increase may be much greater than in the case of the cereals ; whilst in the case of the leguminosæ the effects of such direct application of soluble nitrogenous manures to the surface soil is comparatively so small, and so uncertain, that it would be useless to give an estimate of the amounts recovered and not recovered respectively.

But what becomes of the one-half or two-thirds of the nitrogen supplied for the increased growth of the cereals, but not recovered in the increase of crop? Dr. Frankland and Dr. Voelcker have made numerous analyses of the drainage water from the experimental wheat plots which have yielded the results above referred to, and a summary of their results is given in Table X.

TABLE X.

Nitrogen as Nitrates and Nitrites, per 100,000 parts of Drainage Water from Plots differently manured, in the Experimental Wheat Field at Rothamsted, Wheat every year, commencing 1844.

Manuring, Quantities per acre, per annum.	Nitrogen as Nitrates and Nitrites, per 100,000 parts Drainage Water.					
	Dr. Frankland's Results.		Dr. Voelcker's Results.		Mean.	
	Experi- ments.		Experi- ments.		Experi- ments.	
Farm-yard Manure	4	0·922	2	1·606	6	1·264
Without Manure	6	0·316	5	0·390	11	0·353
Complex Mineral Manure. .	6	0·349	5	0·506	11	0·428
Complex Min. Man. & 41 lbs. Nitrogen, as Ammonia . . }	6	0·793	5	0·853	11	0·823
Complex Min. Man. & 82 lbs. Nitrogen, as Ammonia . . }	6	1·477	5	1·400	11	1·439
Complex Min. Man. & 123 lbs. Nitrogen, as Ammonia . . }	6	1·951	5	1·679	11	1·815
Complex Min. Man. & 82 lbs. Nitrogen, as Nitrate . . . }	5	1·039	5	1·835	10	1·437

The figures in the Table conclusively show that the quantity of nitrogen as nitrates per 100,000 parts of the drainage water, increased in very direct proportion to the increase in the amount of ammonia or nitrate supplied, and it is obvious that there has been a considerable loss of the nitrogen of the manures by drainage. But as the subsoil rests upon chalk not many feet below the surface, and there is, therefore, natural drainage constantly going on, even when there is no flow from the pipes, it is impossible accurately to estimate the total amount of drainage, and therefrom the total amount of loss. Other experiments at Rothamsted, however, lead to the conclusion that, according to season, from one-quarter to nearly one-half of the annual rainfall may pass below 40 inches. Now, supposing drainage water to contain one part of nitrogen as nitrates per 100,000 parts of water, an inch of rain passing beyond the reach of the roots would carry with it $2\frac{1}{4}$ lbs. of nitrogen per acre; and it is obvious that if from seven to ten inches passed annually of that average strength, the loss would be very great. In reference to this point it is of much interest to observe, that in the Report of the River's Pollution Commission already referred to, Dr. Frankland gives a series of analyses of land drainage waters collected at Rothamsted, at depths of twenty, forty, and sixty inches, respectively; and those collected at twenty inches, almost invariably show much more nitrogen as nitric acid than those taken at either forty or sixty inches. It would thus appear to be indicated that a considerable amount of nitric acid has been arrested in the soil below the depth of twenty inches. Further, determinations of nitrogen in the soils do show some accumulation. Indeed, it would appear probable, that the whole of the nitrogen applied to the wheat as ammonia salts or nitrate of soda, was either recovered in the increase of crop, or may be accounted for by determinable accumulation within the soil, or by loss by drainage.

In ordinary agriculture, the amounts of soluble nitrogenous manures applied would generally be much less than in some of these special experiments; and the losses by drainage would from that cause alone be proportionately less than that shown above. Much, obviously, would also depend upon the character of the soil and of the subsoil. Again, in an ordinary rotation of crops, more of the supplied nitrogen would probably be gathered up before it reached the lower layers, than in the case of a cereal crop grown year after year on the same land. It may be safely concluded, however, that whenever cereals were grown, a material proportion of the nitrogen specially applied to, or

existing in the soil, which would be available to other crops, would not be so to them ; but would in the first instance accumulate in the surface soil, and gradually pass into the lower layers in the form of nitrates, to be eventually lost by drainage if not arrested by some other crop.

The question obviously arises, whether we have not here a source of some at least of the nitrogen available to leguminous or to other plants having possession by their roots of a greater range of subsoil than the gramineæ. We have evidence enough that although wheat and barley send roots down very deep into the subsoil, and pump up moisture from the deeper layers, they nevertheless derive much of their nitrogen within the surface soil. If the leguminosæ do not so readily do so, or at any rate naturally depend more upon the nitrogen in the lower layers for a considerable proportion of that which they require, and moreover are able to avail themselves of the residue from the manuring for other crops, what is the nature of the problem that we may have to solve to elucidate this point ?

By way of illustration it may be mentioned that, supposing a leguminous crop to acquire 100 lbs. of nitrogen per acre from a layer of subsoil three feet in thickness, weighing approximately 10,000,000 lbs. (exclusive of stones and water), this would represent only '001 per cent. of nitrogen so acquired in such subsoil ; 200 lbs. of nitrogen per acre so available would represent '002 per cent., and so on. Now, even supposing that the nitrogen existed in the subsoil in such a condition as to be converted into ammonia in the process of combustion with soda-lime, the difference between one subsoil containing this, or even a larger amount of nitrogen, more than another, could not with certainty be determined by that process ; for, in taking say 15 or 20 grams of the subsoil for combustion, the difference between two or more determinations could not be expected to be less than some units in the third decimal place (per cent.) ; that is, in fact, equal to the total amount that may be in question as between two subsoils to be compared. Further, if this available nitrogen exist in the subsoil as nitrates, it may be a question whether there would be a sufficient amount of organic matter present to insure the evolution as ammonia of the nitrogen of the nitric acid.

It has been shown, then, that there are many questions still open for investigation in regard to the relations of the surface soil to combined nitrogen ; and there are obviously also equally important points to investigate in regard to the nitrogen of the sub-soil, before we can hope to arrive at a satisfactory solution of some of the problems which the

consideration of the facts of vegetable production which have been adduced, suggest for enquiry. Nor are the problems still open connected with the amount, and the condition, of the mineral food of plants within the soil, either few, or without special, and independent interest. And although those relating to the nitrogen seem to call for the first attention, the marked effects, so far, of potass manures, in increasing the amount of nitrogen assimilated over a given area by the leguminosæ, seem to indicate the probability that even the difficulties connected with the sources of the nitrogen of our crops may not be solved without further knowledge as to the required conditions, or the actions, of the incombustible or mineral constituents in soils.

Our results in regard to the variations in the amount of nitrogen in the soils and subsoils of our different experimental plots, obtained by the soda-lime process, together with the results already referred to, relating to the composition of the drainage water from plots variously manured, as well as others of quite a different kind, have shown the absolute necessity for an extended investigation of the soil question by more exact methods; and Mr. Warington is about to devote, probably some years, to this enquiry at Rothamsted. It is proposed that the questions relating to the nitrogen in subsoils should be the first considered, as, if the results do throw light upon some of the points at present in doubt, a definite step in advance will be so gained; and should they not do so, the ground will thus be cleared of certain obvious suppositions, and the course of further research will be the more clearly indicated. But if the amount of nitrogen to be discriminated should prove to be represented by only units in the third decimal place per cent, say '002 for example, it is obvious that to get as little as four milligrams involved in the analysis, 200 grams of soil would have to be operated upon. The difficulties of the problem are thus sufficiently obvious. But, by the aid of the processes of water and gas analysis which have been explained by the President in his opening address, there is little doubt that they can be overcome, at any rate so far as the nitrogen existing as nitric acid is concerned; and by the kindness of Dr. Frankland, Mr. Warington is at the present time gaining experience in the use of those methods, in the laboratory of the College of Chemistry, before entering upon this special investigation at Rothamsted.

But even supposing we arrive at a satisfactory solution of the, at present, unsettled points in regard to the sources of the nitrogen yielded in agricultural production, when, as in the experiments to

which attention has been directed, we have a soil to work upon which already contains accumulations of combined nitrogen amounting to several thousands of pounds per acre within the range of the roots of our crops, further questions in regard to the nitrogen may still be left open, namely,—to what actions a large proportion of the existing combined nitrogen may be attributed ; and what in particular is the exact source of the accumulations of it in our soils and subsoils ? And here it may be observed, in passing, that determinations made at Rothamsted have shown approximately the same percentage of nitrogen in the Oxford-clay obtained in the recent Sub-Wealden exploration boring at a depth of between 500 and 600 feet, and in the subsoil at Rothamsted, taken a depth of about 4 feet only.

It is not within the scope of the present discourse to discuss fully what is known of the actual or possible sources of the already existing combined nitrogen, the special object of the enquiry being, as intimated at the commencement, to bring to view the facts relating to the yield of nitrogen in agricultural production, which the extended period of the investigations of Mr. Lawes and myself have enabled us to establish, and to point out the relation of this to the various known or supposed sources of present periodic supplies, so as to indicate what points seem the most urgently to demand further investigation. In the papers already referred to, we have more fully considered what was known of the various actual or possible sources of the combined nitrogen which we know to exist, and to circulate, in land and water, in animal and vegetable life, and in the atmosphere, and we have pointed out how little was established of either the actual or the relative importance, in a *quantitative* sense, of the various actions by which it is admitted that free nitrogen may in nature be brought into combination. I may, however, observe that M. Boussingault and M. Schlösing have quite recently made interesting contributions to the discussion of this subject. (Compt. Rend. T. lxxvi, lxxx, lxxxi, and lxxxii).

But whatever may be the origin of the existing combined nitrogen, or whether or not the agencies of its formation are more or less active now than during the earlier history of the earth and its atmosphere, the question arises whether, assuming the origin to be independent of the direct action of vegetation, the large accumulations within our soils and subsoils, admits of any reasonable explanation ? On this point it may be remarked, that ages of forest growth, or of the growth of natural herbage only grazed by animals, would doubtless leave the soil richer year by year ; as the amount annually lost to it would probably

be less than even the small amount known to be annually deposited from the atmosphere, in temperate regions, at the present time ; and the accumulation would probably be greater still, were the amounts of combined nitrogen in the atmosphere, and brought down from it, greater than with us at the present time. Then, again, the influence on aqueous deposits of ages of submarine vegetation, and of the subsistence of animal life upon it, has to be considered. But a soil once broken up, and under arable culture, it is difficult to conceive of any system of agriculture by which so little nitrogen as that hitherto quantitatively determined to be annually deposited from the atmosphere would be annually exported from the land.

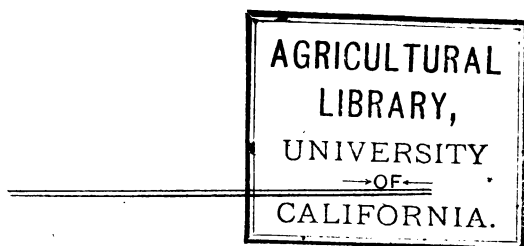
And now, to summarise in a few words the results of the whole discussion, I think the balance of the evidence points to the conclusion, that the answer to the question—what are the sources of the nitrogen of vegetation in general, and of agricultural production in particular, is more likely to be found in the relations of the atmosphere, and of the plant, to the soil, than in those of the atmosphere to the plant itself.

One word more in conclusion. I have, as explained at the outset, confined attention almost exclusively to one aspect of the great subject of vegetation ; but it will not be supposed that I have done so from any want of appreciation of the interest and importance of other lines of enquiry ; and allow me, before closing to allude to a point which can hardly fail to suggest itself on an inspection of the numerous organic compounds, made by transformation in the laboratory, which are collected in the Chemical Section of this Exhibition. Without in the least degree disparaging such work, I would ask whether some of those who have become masters of such transformations, might not with advantage, armed with the experience thus gained, now devote themselves to the study of the transformations going on within the plant and the animal ? In other words, whether it would not be desirable, that some of the thought and labour now expended on transformations in the chemical laboratory should be transferred to the laboratory of nature ?

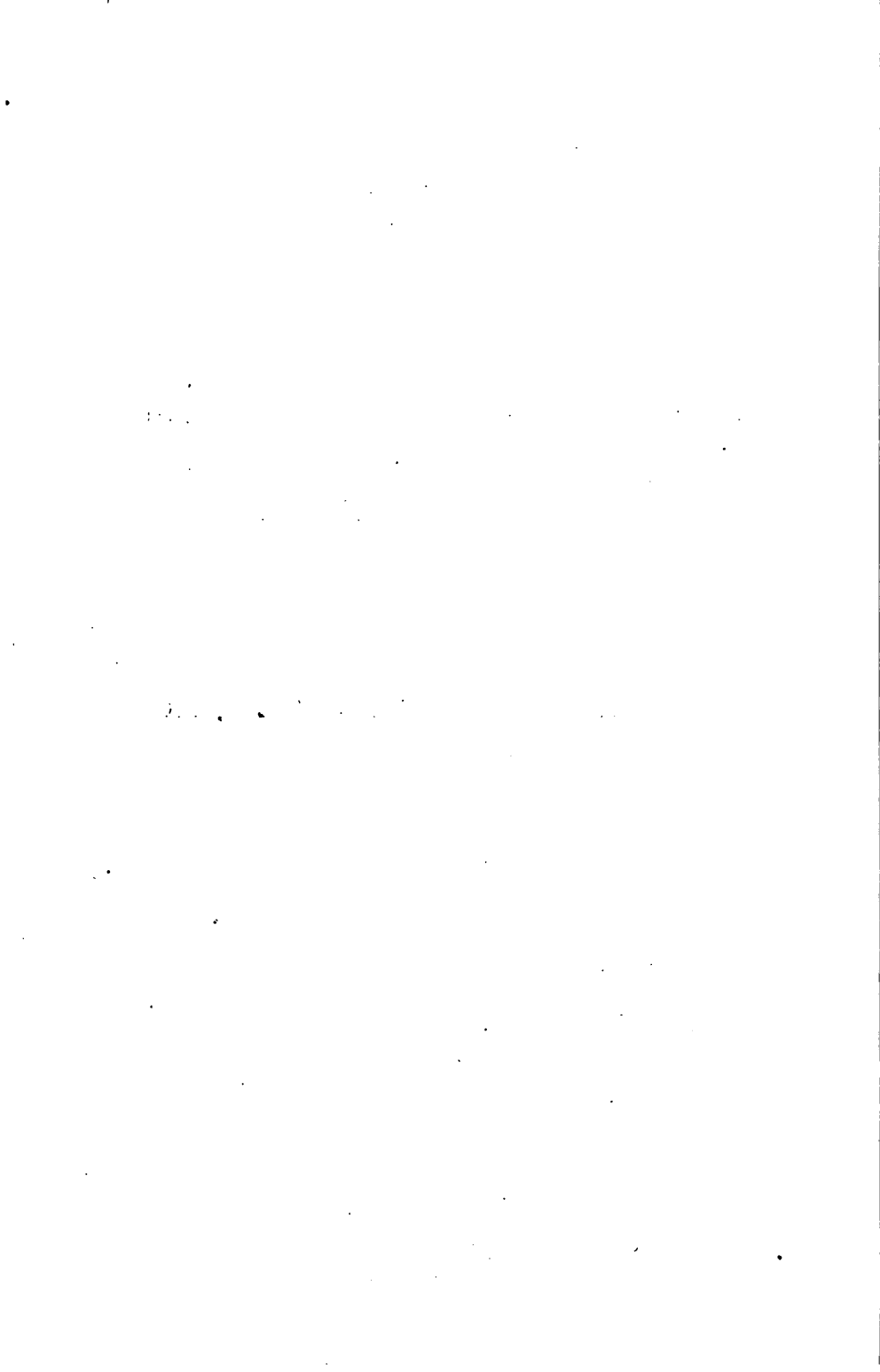
ON SOME POINTS IN CONNECTION WITH ANIMAL NUTRITION.

BEING AN ADDRESS DELIVERED AT SOUTH KENSINGTON,
IN THE BIOLOGICAL SECTION OF THE
SCIENCE CONFERENCES, MAY 26, 1876.

BY DR. J. H. GILBERT, F.R.S., F.L.S., F.C.S.



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ON SOME POINTS IN CONNECTION WITH ANIMAL NUTRITION.

BY DR. J. H. GILBERT, F.R.S., F.L.S., F.C.S.

A few days ago Professor M. Foster wrote to me to say that he intended to bring the subject of nutrition forward on this occasion, and asked me if I would take part in the discussion afterwards ; and as he and I had had a good deal of correspondence and conversation some little time since about the important question of the sources of the fat of the animal body, I concluded it was probably to that subject he wished me to devote my attention. At any rate, I looked up hurriedly the materials which Mr. Lawes and myself have collected in relation to that subject, and some allied points, and propose, with your permission, to lay the facts before you shortly, although Professor Foster has not given you his paper.

Thirty-five years ago, or more, I believe the view generally accepted was, that the carnivora found the fat which existed in their bodies ready-formed in the herbivorous animals they consumed, and that the herbivora in their turn found all the fat of their bodies ready stored up in the plants they consumed. About that time Liebig, in reviewing the composition of vegetable food, came to the conclusion that this was simply impossible, taking into consideration the amount of fat which was stored up by many animals in proportion to the known quantities in the food. He put forward the view that the carbohydrates of the food—starch, sugar, and so on—were important sources of the fat of the herbivora. For a short time this view was opposed, but only for a short time, by Dumas and Boussingault, and some other experimenters in France, though they afterwards accepted it.

The investigations of Mr. Lawes and myself, it must be borne in mind, have always had an agricultural object, so that if they were not conducted exactly in the way which the physiologist will say they might have been, it has been because we had not the same object before us, that is a purely physiological one. Very soon our own experiments led us to believe that Liebig was right in his conclusion on this point, but that he must be wrong on some other points in relation to the feeding of animals which he so ably discussed. We found it was pretty certain, from the consideration of the feeding experiments, that some of the fat must have the source which he assumed.

On the other hand, he assumed that the value of food to the animal was measured by the amount of nitrogen which it contained ; that is to say, he maintained that, in the formation of meat, in the formation of milk, and in the exercise of force, the measure of the value of the food required, for these purposes, was the amount of nitrogen it contained ; and in the case of the exercise of force, the amount of urea which was eliminated. We found, however, that we could give twice or three times the quantity of nitrogen within a given time to one animal as to another, both at rest, and that the amount of nitrogen eliminated in urea was almost proportional to the amount of nitrogen in the food, and had no direct connection with the amount of force exercised.

The question of which of the constituents in the food, were of the most importance for the exercise of force, and for the making of fat, remained in this condition until the experiments instituted in Munich, about 16 or 17 years ago, with Pettenkofer's beautifully contrived respiration apparatus, a model and drawings of modifications of which are in the next room. I am glad that after very much trouble on my part to get such an apparatus brought to this Exhibition, and entirely failing, it has after all been sent by some one. It consists of a chamber in which an animal can be put, and by a water wheel, or by some other power, the air is gently aspirated through the apparatus, then it passes through guages, and through solutions, which absorb the carbonic acid, &c., and so the amount of air passing is gauged, and the products of respiration are determined. It is not the apparatus itself, but the results which it has brought out, which I wish to refer to on this occasion. In 1860, Bischoff and Voit published their first results. They kept a dog for many months without change as to movement, without giving it any special exercise, but varied its food immensely, and they found the urea eliminated was almost in proportion to the amount of nitrogen taken in the food. But inasmuch as the then existing view required this to be connected in some way with the exercise of force, they explained that so much more force was exercised in the actions within the body in dealing with the increased amount of nitrogenous substance consumed ; so that after all the amount of the urea eliminated was a measure of the exercise of force, although it was in these internal actions, and not in the voluntary exercise of muscular power. I was in Germany at the time that book came out, and went to Munich, hoping to see these gentlemen on the subject. In conversation with Professor Voit, I ventured to call in question the

conclusion at which they had arrived, and I think he considered I was entirely in error. But a few years afterwards it was found by others also that the amount of urea eliminated had no direct connection with the amount of force exercised, and that what is the most pronounced when there is an increased exercise of force, is an increased elimination of carbonic acid by the lungs. I believe there is now no doubt about that matter. Messrs. Fick and Wislicenus, Dr. Frankland, and Dr. E. Smith, brought that prominently forward, and I believe it is now accepted that the elimination of urea is no measure of the muscular force exerted within the body.

After putting forward these views, Messrs. Bischoff and Voit put their dog into a kind of tread-wheel, and they found that the amount of urea eliminated was not in proportion to the exercise of force, but the amount of carbonic acid was so, and eventually they themselves admitted the truth of this.

Then came the question of the sources of animal fat. On this point, again, Voit has worked almost exclusively with the dog, which is a carnivorous, or, at most, an omnivorous animal. He has found, which I do not wish to call in question, that in the case of the carnivora, and in some cases of the herbivora, the fat may be formed from the nitrogenous substance of the food. But from the results obtained with this carnivorous animal he has come to the conclusion, that not only in such cases, but in all, the fat formed within the animal is derived from the albuminous substance of the food or of the body. I have roughly noted a few of the experiments of Voit, which I believe are the strongest or most conclusive for his view of the question. He found that when a dog was fed on starch or sugar alone, or with albumin, or with fat and albumin, the carbon stored up, that is to say, the carbon which was not eliminated in any way from the body, was never more than that in the fat of the food, *plus* that in the albumin which was broken up, as indicated by the amount of urea eliminated. He concluded that this was a proof that fat was not formed from the carbohydrates. In another case, which perhaps was stronger, he fed the dog with starch and a little fat, but no albumin whatever, and the carbon stored up was equal to that of the fat in the food, *plus* that due to the oxidation of albuminous tissue, and when he gave more starch to this food the amount of carbon stored up was reduced; that is to say, he argues that the carbohydrates in this case protected the albumin of the body from disintegration, and did not in any way serve for the production of fat; and that there would have been a greater storing

up of carbon if this additional starch which he gave to the animal had been the source of the fat. He also argued, from a number of experiments, that starch and sugar are quite oxidised in the body, yielding carbonic acid, &c., within twenty-four hours. He maintains that the same must occur with herbivora as with carnivora. The carnivora are found absolutely to digest vegetable food, and take it into their system as an herbivorous animal; and he argues that, to establish a different source of fat, it must be shewn by experiment that fat is formed in excess of that in the food, *plus* that which can be formed from the oxidated albumin. Now this, I think, I shall be able to show you we have done. We have not accepted the challenge in the way of making new experiments for the purpose, but I think we have old experiments which are perfectly conclusive, and do meet exactly the requirement which Voit says is essential to disprove the view which he maintains with regard to the herbivora.

But before entering on our own experiments, I will just say what has happened in answer to the challenge in Germany. Weiske and Wildt conceived, as I shall be able to show afterwards was a very right thing to conceive, that the pig was the very best animal to experiment on for this purpose. He is certainly *the* fat-maker of all the animals that we feed; and there are other reasons why he is the best of all others to experiment upon in this particular. They had, from a theoretical point of view, a very good conception of what was necessary. They took four pigs, slaughtered two of them, and determined the fat and other constituents in those animals. Then they fed one on food very poor in nitrogenous substance, and one on food exceedingly rich in nitrogenous substance. It happened that the pig fed on food very rich in nitrogen had so much that it became unwell, and that experiment failed entirely. With regard to the one fed on food poor in nitrogen, the food was so poor that the experiment took too long a time; in fact, too much food was passed through the body in proportion to the increase produced; and when eventually they slaughtered that animal, and analysed it, so much nitrogen had passed through the body during the time, that they found the whole of the fat that had been formed might be derived from the nitrogenous substance consumed. Weiske and Wildt did not conclude therefrom that it was established that fat could only be produced from the nitrogenous substance, but they admit that the experiment was not conclusive.

In the experiments of Mr. Lawes and myself we have used a great many animals, and we have brought our results into calculation,

although the experiments were not at the time arranged with the special view of determining this question. The table shows some results of experiments with sixteen oxen, 249 sheep, and fifty-nine pigs. You will see that the proportion of stomachs and contents, in the body is 11·6 per cent. with the oxen, 7·5 with sheep, whilst it is only 1·3 in the pig. The intestines and contents, on the other hand, shew in oxen only 2·7, in sheep 3·6, and in the pig 6·2 per cent.; with it, therefore, very much more than with either of the ruminant animals. We know that the character of the food is such in the case of the ruminants that they must pass an enormous quantity of very crude stuff through their bodies, and must elaborate it first in one stomach and then in another, and the result is they have not only a very large capacity of stomach, but also a very large proportion of contents in relation to the whole body. In the case of the pig, on the other hand, the stomach is exceedingly small; the natural food of the pig is starchy seeds or roots (which are the food of man also), it contains exceedingly little necessarily effete matter, their stomachs have comparatively manageable stuff to deal with, and they have a very small stomach, while on the other hand their intestines are very large. It is known that the transformation of the starch goes on almost throughout the intestinal canal, so that we can easily understand how it is that with such starchy food these animals have an enormous amount of intestines compared with either oxen or sheep. If we look at the proportion in the live weight of the, so to speak, further elaborating organs the heart, the liver, the lungs, the pancreas, and so on, their percentage by weight in the bodies of the three descriptions of animals is almost identical.

Now, for 100 lbs. of live weight the amount of dry substance consumed per week was 12·5 by oxen, 16 by sheep, and 27 by pigs; that is : 100 lbs. live weight of pig will consume much more dry substance of food, and, as I have stated, that food is of a more highly nutritive kind, and more easily digested, than that of oxen or sheep. Again, the increase per week was only 1·13 per cent. on the live weight of oxen, 1·76 of sheep, and 6·43 of pigs. So that the proportion of the increase to the weight of the body is much the greatest with the pig. Then, if we take the facts in relation to the amount of the food, for 100 lbs. of dry substance of food, the ox will give in increase only 5·2 of fat, the sheep 7, and the pig 15·7. Suffice it to say, that there is less effete matter in the food of the pig, and therefore its live weight and its increase indicate more nearly the real increase of the body, and

not the fluctuating matters in the alimentary canal. Its food is of a higher character, so that a larger proportion of it is stored up. That which passes through the system is more completely used, and the amount of fat which is produced is also very much higher. Therefore, I say the pig is by far the best animal to experiment upon for this purpose.

Whilst on this subject I may refer to a portion of the table which vegetarians will perhaps not be much pleased to see. If we are to judge that the size of the stomach indicates to some extent the character of the food, its crudeness or concentration, as no doubt is the case with the other animals, and if we compare oxen, sheep, pigs, and man, we find the proportion of stomach by weight per cent. is, approximately, in oxen 3·2, in sheep 2·44, in pigs about 0·88, and in man only 0·38; so that going from one animal to the other you should have more concentrated and more digestible food in the case of man, than of the pig; and you have animal food as well as starchy seeds, roots, &c.; and the indication is, I think, that man was not made to consume potatoes and cabbages by the bushel.

The next point is as to the indications of merely practical results. Without going into the chemistry of the subject, or discussing whether the food of the animal does contain enough or not enough of nitrogenous substances to yield all the fat produced, I will call attention to some results which will indicate the general relations of the food to the necessities of the body. On the coloured diagram you have the results of thirty separate experiments on pigs. The plan was this: we gave to a certain set a fixed amount of highly nitrogenous food, and let them take whatever they liked of less nitrogenous food. To another set we gave a fixed amount of food low in nitrogen and rich in starch and such matters, and let them make up whatever they wanted with highly nitrogenous food. So we rang the changes in a great many more cases than are here represented, but in this way it will be seen that the animal fixed its own diet according to the necessities of the case; and the question is, was it the nitrogenous substances, was it the non-nitrogenous substances, or was it the total dry substance, nitrogenous and non-nitrogenous together, which guided the amount consumed by a given live weight within a given time, or rather guided — for these were fattening animals — the amount of increase which was produced? The lowest amount of nitrogenous substances consumed by 100 lbs. of live weight of pig per week in any one experiment being taken as 100, in some cases 300 were taken, and

in most more than 200. In the same way the lowest amount of non-nitrogenous substance being taken as 100, in no case was nearly as much as 200 consumed, and the average was about 140 parts. When we come to the total dry substance, including both nitrogenous and non-nitrogenous, we find that the quantities ranged more closely together; that is to say, the total digestible organic substance seems to have been the measure of what was required, and that the nitrogenous might possibly act for the non-nitrogenous substances if there were not enough of them. But it is quite clear that the measure was either the non-nitrogenous substances or the total organic substances—certainly not the nitrogenous substances. Then the question arose, whether the same thing would hold in relation to the amount of increase in the weight of animal produced. It was always assumed, I think, until these experiments of Mr. Lawes and myself, that when animals were not fed on highly nitrogenous food the amount they stored up was comparatively small. These experiments show the amount of these three classes of constituents consumed in producing 100 pounds increase of live weight in the different cases. 100 pounds being the lowest amount of nitrogenous substance required, 282 was the highest, the animal fixing his own diet, and in many cases it was over 200; that is to say, more than twice as much as satisfied him when he had enough of other matters to make up. At any rate it would seem that fat can be formed from nitrogenous substances, provided there is a deficiency of non-nitrogenous substances in the food; and I may say that the nitrogenous substances are of a higher food capacity, irrespective of the nitrogen, containing more carbon, more hydrogen, and less oxygen; they have more useful matter in them than an equal weight of starch or any substance of that kind.

Now the question arises, what is the state of affairs when we attempt to calculate these results and to see whether or not the food did contain enough nitrogenous substances, or albuminous matter, to supply the whole of the fat produced? These experiments were not specially arranged to settle that question, but they were calculated afterwards. It was about twenty-six years ago that we took two pigs of the same litter, very carefully selected both by practical and scientific eyes as being as nearly as possible exactly alike. One was slaughtered, and the total amount of dry matter, fat, nitrogen, mineral matter, and so on, determined; and then the other animal was fed. At that time we had not arrived at such distinct conclusions as we did afterwards as to

the desirability of giving a greater proportion of starchy matters. We gave the animal a great deal more than the proportion of nitrogenous substances existing in what may be called the normal fattening food of the pig—barley meal. In the first column of the table, the results of that experiment are calculated out to show whether the food did contain enough nitrogenous matter to yield the fat produced. You will see the proportion of non-nitrogenous matter to one of nitrogenous is 3·6. Now, the proportion in barley meal, which is the best fattening food for the pig, is between 5 and 6 to 1; so that we gave too much nitrogen according to what we now know is the best proportion. There was a considerable amount of increase in ten weeks, eighty-eight pounds, or 85·4 per cent. on the original weight of the body.

The question is, how much fat was in the food? and that is shown in the second division of the table. It is calculated that for 100 pounds increase in the live-weight there were stored up 63·1 pounds of fat. There were of ready-formed fat in the food 15·6 pounds; leaving 47·5 pounds fat to be produced from some material or other. Out of 100 of nitrogenous substances consumed as food, there were stored up in increase 7·8, leaving 92·2 parts of nitrogenous substance which might be used for the production of fat or might not. If we calculate how much carbon there was in the produced fat, and how much there was left available in the nitrogenous substance for the production of fat, we find that there were 7·4 pounds more carbon possibly available from the nitrogenous substance than was necessary for the production of the fat; or, put in another way, there were 120 of carbon available from the nitrogenous substances for 100 required.

According to this mode of calculation, therefore, there was enough nitrogenous substance to justify the conclusion of Voit; or rather, the result does not in any way disprove his conclusion that fat has been produced from the disintegration of nitrogenous substances in the body. This table was calculated some years ago, and we have intentionally put the results in the worst aspect that we could for our own side of the case, that we might not exaggerate the conditions. For instance, we have assumed that the whole of the fat in the food would be taken up, which it certainly would not; and we have assumed that the whole of the nitrogenous substances of the food would be digested, and would come into play, which they certainly would not. If we assume in our own calculations the estimate adopted in Germany, that 100 pounds of nitrogenous substance cannot yield more than

fifty-one of fat, even this experiment shows a little deficiency of nitrogenous substances, and would in fact be in favour of our view.

The next two experiments given in the table show a still higher proportion of nitrogenous substance in the food; and there was, accordingly, a great deal more carbon available from the nitrogenous substance than was necessary for the formation of the amount of fat produced.

The next two experiments (four and five), were with more natural fattening food of the animal, one entirely Indian corn-meal, and the other entirely barley-meal. A pig requires for rapid fattening very little, if any, more nitrogenous substance than this represents. But here we have only 60 per cent. or a little over, 60·8 in one case, and 60·5 in the other, of the carbon of the fat produced in the animal, possibly derivable from the nitrogenous substance of the food. So that we have in those two cases nearly 40 per cent. of the carbon of the produced fat which could not possibly come from the nitrogenous substances, and must have come from the non-nitrogenous matter, in fact from the carbohydrates. But an objection may be raised to this calculation; the animals were larger to begin with; and the weights were heavier at the end; so that the composition of the lean animal, and of the fat animal, as derived from the direct analyses, does not absolutely apply; but we could not possibly thus get rid of this forty or more per cent. which the calculations would show to be derived from the non-nitrogenous substance of the food.

The remaining four experiments are also entirely in favour of our view. The animals were about the same weights as those analysed: the food was more nearly the proper food for fattening, being rather lower in nitrogenous substances, but much higher than in experiments 4 and 5. But even here we found 18·9, 18·8, 25·2, and 14·1 per cent. of the total carbon of the produced fat could not possibly have been derived, and certainly a great deal more was not derived, from the nitrogenous substances of the food.

I need not trouble you further with these results. But I should say that the contrary view has been adopted not only by some physiologists, but in Germany in some text books on agricultural chemistry. I hold in my hand one of these text books in which the evidence of these experiments is discarded, and it is assumed that if you cannot experiment with the respiration apparatus the results are good for nothing. I would not wish to depreciate the importance of the results obtained by the respiration apparatus in any way. I have taken the

greatest interest in them, and I think they lead to the most important conclusions; but I also think some observers have come to very erroneous conclusions from the results of such experiments. I submit that if you experiment with *the* fat-producer—the pig—and if you take two carefully selected animals (or more if you like) kill and analyse one, and feed the other as rapidly as possible, that is, let him take as much of the most appropriate food as he will take, you may, without any respiration apparatus, determine this point. It is most important that it should be definitely settled. Since the recent publications on the subject, Mr. Lawes and myself have gone thoroughly into the question, and re-calculated most of our results; those relating to oxen and sheep as well as pigs. They point to this: that the ruminant animals, which have such elaborate machinery, and do so little productive work, do pass so much nitrogenous substance through the body in relation to the amount of increase, that they do not show that fat can be derived from the non-nitrogenous substances of the food; but in the case of pigs the evidence is perfectly conclusive. Having re-calculated our own experiments in this way, and the results being absolutely conclusive so far as the pig is concerned, Mr. Lawes is unwilling to be at the trouble and expense of further experiments on the question; but it really is one of great importance, and one which public institutions might well take up. It is of importance, not only agriculturally, with reference to the proper way of feeding stock, but also in its bearings on the nutrition of man.

[For the tables and diagrams referred to above, see—"On the Sources of the Fat of the Animal Body," *Philosophical Magazine*, December, 1866; and—"On the Formation of Fat in the Animal Body," *Journal of Anatomy and Physiology*, Vol. xi., Part iv.; and for other points, and detail—"Food in its Relations to Various Exigencies of the Animal Body," *Philosophical Magazine*, July, 1866; and the papers therein referred to.]

BRITISH ASSOCIATION,

SWANSEA, 1880.

SKETCH OF THE PROGRESS
OF
AGRICULTURAL CHEMISTRY;

ADDRESS

TO THE

CHEMICAL SECTION.

BY

J. H. GILBERT, PH.D., F.R.S., V.P.C.S., F.I.S.,

President of the Section.

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BY

J. H. GILBERT, *Ph. D., F.R.S., V.P.C.S., F.L.S.*,
PRESIDENT OF THE SECTION.

SOME of my predecessors in this Chair, whose duties as teachers of chemistry lead them to traverse a wide range of the subject every year, have appropriately and usefully presented to the Section a *résumé* of the then recent progress in the manifold branches of the science which have now such far-reaching ramifications. Such a course has, however, come to be of much less importance and interest of late years, since the systematic publication by the Chemical Society of abstracts of chemical papers in home and foreign journals as soon as possible after their appearance. Some, on the other hand, have confined attention to a department with which their own inquiries have more specially connected them. And, when the Council of the Association request a specialist like myself to undertake the Presidency of the Section, it is to be supposed they take it for granted that he will select for his opening address some branch of the subject with which he is known to be mainly associated.

But it seems to me that there is a special reason why I should bring the subject of Agricultural Chemistry before you on the present occasion. Not only is the application of chemistry to agriculture included in the title of this Section; but in 1837 the Committee of the Section requested the late Baron Liebig to prepare a report upon the then condition of Organic Chemistry, and it is now exactly forty years since Liebig presented to the British Association the first part of his report, which was entitled *Organic Chemistry in its Applications to Agriculture and Physiology*; and the second part was presented two years later, in 1842, under the title of *Animal Chemistry, or Organic Chemistry in its application to Physiology and Pathology*. Yet, so far as I am aware, no President of the Section has, from that time to the present, taken as the subject of his address the Application of Chemistry to Agriculture.

Appropriate as, for these reasons, it would seem that I, who have devoted a very large portion of the interval since the publication of Liebig's works, above referred

to, to agricultural enquiries, should occupy the short time that can be devoted to such a purpose in attempting to note progress on that important subject, it will be readily understood that it would be quite impossible to condense into the limits of an hour's discourse anything approaching to an adequate account, either of the progress made during the last forty years, or of the existing condition of agricultural chemistry.

For what is agricultural chemistry? It is the chemistry of the atmosphere; the chemistry of the soil; the chemistry of vegetation; and the chemistry of animal life and growth. And but a very imperfect indication of the amount of labour which has been devoted of recent years to the investigation of these various branches of what might at first sight seem a limited subject, will suffice to convince you how hopeless a task it would be to seek to do more than direct attention to a few points of special interest. Indeed, devoting to the purpose such leisure as I have been able to command, the more I have attempted to become acquainted with the vast literature which has been accumulated on the subject, the more difficulty have I felt in making a selection of illustrations which should not convey an idea of the limits, rather than of the extent, of the labour which has been expended, and of the results which have been attained, in agricultural research.

The works of Liebig to which I have referred have, as you all know, been the subject of a very great deal of controversy. Agricultural chemists, vegetable physiologists, and animal physiologists, have each vehemently opposed some of the conclusions of the author, bearing upon their respective branches. But, if the part which has fallen to my own lot in these discussions qualifies me at all to speak for others as well as myself, I would say that those who, having themselves carefully investigated the points in question, have the most prominently dissented from any special views put forward in those works, will—whether they be agricultural chemists, vegetable physiologists, or animal physiologists—be the first to admit how vast has been the stimulus, and how important has been the direction, given to research in their own department, by the masterly review of then existing knowledge, and the bold, and frequently sagacious, generalisations of one of the most remarkable men of his time!

Confining attention to researches bearing upon agriculture, it will be well, before attempting to indicate either the position established by Liebig's first works, or the direction of the progress since made, to refer very briefly to the early history of the subject.

From what we now know of the composition and of the sources of the constituents of plants, it is obvious that a knowledge of the composition of the atmosphere, and of water, was essential to any true conception of the main features of the vegetative process; and it is of interest to observe that it was almost simultaneously with the establishment, towards the end of the last century, of definite knowledge as to the composition of the air and of water, that their mutual relations with vegetation were first pointed out. To the collective labours of Black, Scheele, Priestley, Lavoisier, Cavendish, and Watt, we owe the knowledge that common air consists chiefly of nitrogen and oxygen, with a little carbonic acid; that carbonic acid is composed of carbon and oxygen; and that water is composed of hydrogen and oxygen; whilst Priestley and Ingenhousz, Sennebie and Woodhouse, investigated the mutual relations of these bodies and vegetable growth. Priestley observed that plants possessed the faculty of purifying air vitiated by combustion or by the respiration of animals; and, he having discovered oxygen, it was found that the gaseous bubbles which Bonnet had shown to be emitted from the surface of leaves plunged in water consisted principally of that gas. Ingenhousz demonstrated that the action of light was essential to the development of these phenomena; and Sennebie proved that the oxygen emitted resulted from the decomposition of the carbonic acid taken up.

So far, however, attention seems to have been directed more prominently to the question of the influence of plants upon the media with which they were surrounded, than to that of the influence of those media in contributing to the increased substance of the plants themselves. Towards the end of the last century, and in the beginning of the present one, De Saussure followed up these inquiries

and in his work entitled, *Recherches Chimiques sur la Végétation*, published in 1804, he may be said to have indicated, if not indeed established, some of the most important facts with which we are yet acquainted, regarding the sources of the constituents stored up by the growing plant. De Saussure illustrated experimentally, and even to some extent quantitatively, the fact that in sun-light plants increase in carbon, hydrogen, and oxygen, at the expense of carbonic acid and of water; and in the case of his main experiment on the point, he found the increase in carbon, and in the elements of water, to be very closely in the proportion in which these are known to exist in the carbohydrates. He further maintained the essentialness of the mineral or ash constituents of plants; he pointed out that they must be derived from the soil; and he called attention to the probability that the incombustible constituents so derived by plants from the soil, were the source of those found in the animals fed upon them.

With regard to the nitrogen which plants had already been shown to contain, Priestley and Ingenhousz thought their experiments indicated that they absorbed free nitrogen from the atmosphere; but Sennebler and Woodhouse arrived at an opposite conclusion. De Saussure, again, thought that his experiments showed rather an evolution of nitrogen at the expense of the substance of the plant, than any assimilation of it from gaseous media. He further concluded, that the source of the nitrogen of plants was more probably the nitrogenous compounds in the soil, and the small amount of ammonia which he demonstrated to exist in the atmosphere.

Upon the whole, De Saussure concluded that air and water contributed a much larger proportion of the dry substance of plants than did the soils in which they grew. In his view a fertile soil was one which yielded liberally to the plant nitrogenous compounds, and the incombustible or mineral constituents; whilst the carbon, hydrogen, and oxygen, of which the greater proportion of the dry substance of the plant was made up, were at least mainly derived from the air and water.

Perhaps I ought not to omit to mention here that, each year for 10 successive years, from 1802 to 1812, Sir Humphry Davy delivered a course of lectures on the *Elements of Agricultural Chemistry*, which were first published in 1813; were finally revised by the author for the Fourth Edition in 1827, but have gone through several editions since. In those Lectures, Sir Humphry Davy passed in review and correlated the then existing knowledge, both practical and scientific, bearing upon agriculture. He treated of the influences of heat and light; of the organisation of plants; of the difference, and the change, in the chemical composition of their different parts; of the sources, composition, and treatment, of soils; of the composition of the atmosphere, and its influence on vegetation; of the composition and the action of manures; of fermentation and putrefaction; and finally of the principles involved in various recognised agricultural practices.

With the exception of these discourses of Sir Humphry Davy, the subject seems to have received comparatively little attention, nor was any important addition made to our knowledge in regard to it, during the period of about 30 years, from the date of the appearance of De Saussure's work in 1804 to that of the commencement of Boussingault's investigations.¹

About 1834, Boussingault became, by marriage, joint proprietor with his brother-in-law, of the estate of Bechelbronn, in Alsace. His brother-in-law, M. Lebel, was both a chemical manufacturer and an intelligent practical farmer, accustomed to use the balance for the weighing of manures, crops, and cattle. Boussingault seems to have applied himself at once to chemic-agricultural research; and it was under these conditions of the association of 'practice with science' that the first laboratory on a farm was established.

From this time forward, Boussingault generally spent about half the year in Paris, and the other half in Alsace; and he has continued his scientific labours, sometimes in the city, and sometimes in the country, up to the present time. His

¹ Some reference should have been made in the text to the labours and writings of Dr. Carl Sprengel, late Professor of Agriculture at Brunswick, who made numerous analyses of agricultural materials, and published numerous papers in connection with Agricultural Chemistry, during a series of years, commencing about 1826.

first important contribution to agricultural chemistry was made in 1836, when he published a paper on the amount of nitrogen in different foods, and on the equivalence of the foods, founded on the amounts of nitrogen they contained; and he compared the results so arrived at with the estimates of others founded on actual experience. Although his conclusions on the subject have doubtless undergone modification since that time, the work itself marked a great advance on previously existing knowledge, and modes of viewing the question.

In 1837, Boussingault published papers—on the amount of gluten in different kinds of wheat; on the influence of the clearing of forests on the diminution of the flow of rivers; and on the meteorological influences affecting the culture of the vine. In 1838 he published the results of an elaborate research on the principles underlying the value of a rotation of crops. He determined by analysis the composition, both organic and inorganic, of the manures applied to the land, and of the crops harvested. In his treatment of the subject he evinced a clear perception of the most important problems involved in such an inquiry; some of which, with the united labours of himself and many other workers, have scarcely yet received an undisputed solution.

Thus, in the same year (1838), he published the results of an investigation on the question whether plants assimilate the free or uncombined nitrogen of the atmosphere; and although the analytical methods of the day were inadequate to the decisive settlement of the point, his conclusions were in the main those which much subsequent work of his own, and much of others also, has served to confirm.

As a further element of the question of the chemical statistics of a rotation of crops, Boussingault determined the amount and composition of the residues of various crops; also the amount of constituents consumed in the food of a cow and of a horse respectively, and yielded in the milk and excretions of the cow, and in the excretions of the horse. Here, again, the exigencies of the investigation he undertook were beyond the reach of the known methods of the time. Indeed, rude as the art of agriculture is generally considered to be, the scientific elucidation of its practices requires the most refined, and very varied, methods of research; and a characteristic of the work of Boussingault may be said to be, that he has frequently had to devise methods suitable to his purpose, before he could grapple with the problems before him.

In 1839, chiefly in recognition of his important contributions to agricultural chemistry, Boussingault was elected a member of the Institute; and in 1878, thirty-nine years later, the Council of the Royal Society awarded to him the Copley Medal, the highest honour at their disposal, for his numerous and varied contributions to science, but especially for those relating to agriculture.

The foregoing brief historical sketch is sufficient to indicate, though but in broad outline, the range of existing knowledge on the subject of agricultural chemistry prior to the appearance of Liebig's memorable work in 1840. It will be seen that some very important and indeed fundamental facts had already been established in regard to vegetation, and that Boussingault had not only extended inquiry on that subject, but he had brought his own and previous results to bear upon the elucidation of long-recognised agricultural practices. There can be no doubt that the data supplied by his researches contributed important elements to the basis of established facts upon which Liebig founded his brilliant generalisations. Accordingly, in 1841, Dumas and Boussingault published, jointly, an essay which afterwards appeared in English under the title of *The Chemical and Physiological Balance of Organic Nature*; and, in 1843, Boussingault published a larger work, which embodied the results of many of his own previous original investigations.

But there can be no doubt that the appearance of Liebig's two works, which were contributions made in answer to a request submitted to him by the committee of this Section of the British Association, constituted a very marked epoch in the history of the progress of agricultural chemistry. In the treatment of his subject he not only called to his aid the previously existing knowledge directly bearing upon it, but he also turned to good account the more recent triumphs of organic chemistry, many of which had been won in his own laboratory. Further, a marked feature of his expositions was the adoption of what may be called the *statistical*

method—I use the word statistical rather than quantitative, as the latter expression has its own technical meaning among chemists, which is not precisely what I wish to convey.

It seems that, notwithstanding the conclusive evidence afforded by the direct experiments of De Saussure and his predecessors, vegetable physiologists continued to hold the view that the humus of the soil was the source of the carbon of vegetation. Not only did Liebig give full weight to the evidence of the experiments of De Saussure and others, and illustrate the possible or probable transformations within the plant by facts already established in organic chemistry, but he demonstrated the utter impossibility of humus supplying the amount of carbon assimilated over a given area. He pointed out that humus itself was the product of previous vegetable growth, and that it could not therefore be an original source of carbon; and that, from the degree of its insolubility, either in pure water or in water containing alkaline or earthy bases, only a small portion of the carbon assimilated by plants could be derived from the amount of humus that could possibly enter the plant in solution. He maintained that, so far as humus was beneficial to vegetation at all, it was only by its oxidation, and a consequent supply of carbonic acid within the soil; a source which he considered only of importance in the early stages of the life of a plant, and before it had developed and exposed a sufficient amount of green surface to the atmosphere to render it independent of soil supplies of carbonic acid.

With regard to the hydrogen of plants, at any rate that portion of it contained in their non-nitrogenous products, he maintained that its source must be water; and that the source of the oxygen was either that contained in carbonic acid or that in water.

With regard to the nitrogen of vegetation, both from the known characters of free nitrogen, and as he considered a legitimate deduction from direct experiments, he argued that plants did not take up free or uncombined nitrogen, either from the atmosphere, or dissolved in water and so absorbed by the roots. The source of the nitrogen of vegetation was, he maintained, ammonia; the product of the putrefaction of one generation of plants and animals affording a supply for its successors. He pointed out that, in the case of a farm receiving nothing from external sources, and selling off certain products, the amount of nitrogen in the manure derived by the consumption of some of the vegetable produce on the farm itself, together with that due to the refuse of the crops, must always be less than was contained in the crops grown; and he concluded that though the quantity so returned to the land was important, a main source of the nitrogen assimilated over a given area was that brought down from the atmosphere in rain.

There can be no doubt that, owing to the limited and defective experimental evidence then at command on the point, Liebig at that time (as he has since) greatly over-estimated the amount of ammonia available to vegetation from that source. In Boussingault's '*réclamation*' already referred to, he gave much more prominence to the importance of the nitrogen of manures. In Liebig's next edition (in 1843) he combated the notion of the relative importance of the nitrogen of manures; maintained, in opposition to the view put forward in his former edition, that the atmosphere afforded a sufficient supply of nitrogen for cultivated as well as for uncultivated plants; that the supply was sufficient for the cereals as well as for leguminous plants: that it was not necessary to supply nitrogen to the former; and he insisted very much more strongly than formerly on the relative importance of the supply of the incombustible, or, as he designated them, the 'inorganic' or 'mineral,' constituents.

As to the incombustible or mineral constituents themselves, Liebig adduced many illustrations in proof of their essentialness. He called attention to the variation in the composition of the ash of plants grown on different soils; and he assumed a greater degree of mutual replaceability of one base by another, or of one acid by another, than could be now admitted. He traced the difference in the mineral composition of different soils to that of the rocks which had been their source; and he seems to have been led by the consideration of the gradual action of '*weathering*,' in rendering available the otherwise locked-up stores, to

attribute the benefits of fallow exclusively to the increased supply of the incombustible constituents which would, by its agency, be brought into a condition in which they could be taken up by plants.

The benefits of an alternation of crops Liebig considered to be in part explained by the influence of the excreted matters from one description of crop upon the growth of another. He did not attach weight to the assumption that such matters would be directly injurious to the same description of crop; but he supposed rather that the matters excreted were those which the plant did not need, and would therefore be of no avail to the same description of plant, but would be of use to another. He, however, attributed much of the benefits of a rotation to different mineral constituents being required from the soil by the respective crops.

Treating of manure, he laid the greatest stress on the return by it of the potash and the phosphates removed by the crops. But he also insisted on the importance of the nitrogen, especially that in the liquid excretions of animals, and condemned the methods of treatment of animal manures by which the ammonia was allowed to be lost by evaporation. It is curious and significant, however, that some of the passages in his first edition, in which he the most forcibly urges the value of the nitrogen of animal manures, are omitted in the third and fourth editions.

The discussion of the processes of fermentation, decay, and putrefaction, and that of poisons, contagions, and miasms, constituted a remarkable and important part of Liebig's first report. It was the portion relating to poisons, contagions, and miasms, that he presented to this Section as an instalment, at the meeting of the Association held at Glasgow in 1840. It was in the chapters relating to the several subjects here enumerated that he developed so prominently his views on the influence of contact in inducing chemical changes. He cited many known transformations, other than those coming under either of the heads in question, in illustration of his subject; and he discussed with great clearness the different conditions occurring, and the different results obtained, in various processes—such as the different modes of fermenting beer, the fermentation of wine from different kinds of grapes, the production of acetic acid, &c. As is well known, he claimed a purely chemical explanation for the phenomena involved in fermentation. He further maintained that the action of contagions was precisely similar. In his latest writings on the subject (in 1870), he admits some change of view; but it is by no means easy to decide exactly how much or how little of modification he would wish to imply.

Liebig's second report, presented at the meeting of this Association in 1842, and published under the title of *Animal Chemistry, or Organic Chemistry in its applications to Physiology and Pathology*, perhaps excited even more attention than his first, and, probably from the manner as much as from the matter, aroused a great deal of controversy, especially among physiologists and physicians. Liebig was severe upon what he considered to be a too exclusive attention to morphological characters in physiological research, and at any rate too little attention to chemical phenomena, and, so far as these were investigated, an inadequate treatment of the subject according to strictly quantitative methods.

He combated the view that nervous action, as such, could be a source of any of the heat of the body; and he adduced numerous illustrations and calculations in support of the view that the combustion of carbon and hydrogen in the system was sufficient to account for, and was the only source of, animal heat.

He compared and contrasted the general composition of plants and animals. In accordance with Mulder, he pointed out that whilst plants formed the nitrogenous bodies which they contain from carbonic acid, water, and ammonia, animals did not produce them, but received them ready-formed in their vegetable food; that, in fact, the animal begins only where the plant ends. But, going beyond Mulder, and beyond what had then, or has since, been established, he maintained the identity in composition of the admittedly analogous nitrogenous compounds in plants and in the blood of animals.

Omitting the fat which the carnivora might receive in the animals they consumed, he stated the characteristic difference between the food of carnivora and herbivora to be, that the former obtained the main proportion of their respiratory

material from the waste of tissue; whilst the latter obtained a large amount from starch, sugar, &c. These different conditions of life accounted for the comparative leanness of carnivora and fatness of herbivora.

He maintained that the vegetable food consumed by herbivora did not contain anything like the amount of fat which they stored up in their bodies; and he showed how nearly the composition of fat was obtained by the simple elimination of so much oxygen, or of oxygen and a little carbonic acid, from the various carbo-hydrates. Much less oxygen would be required to be eliminated from a quantity of fibrine, &c., containing a given amount of carbon, than from a quantity of carbo-hydrates containing an equal amount of carbon. The formation of fatty matter in plants was of the same kind; it was the result of a secondary action, starch being first formed from carbonic acid and water.

He concluded from the facts adduced that the food of man might be divided into the *nitrogenised* and the *non-nitrogenised* elements. The former were capable of conversion into blood, the latter incapable of such transformation. The former might be called the *plastic elements of nutrition*, the latter *elements of respiration*. From the plastic elements, the membranes and cellular tissue, the nerves and brain, cartilage, and the organic part of bones, could be formed; but the plastic substance must be received ready-made. Whilst gelatine or chondrine was derived from fibrine or albumen, fibrine or albumen could not be reproduced from gelatine or chondrine. The gelatinous tissues suffer progressive alteration under the influence of oxygen, and the materials for their re-formation must be restored from the blood. It might, however, be a question whether gelatine taken in food might not again be converted into cellular tissue, membrane, and cartilage, in the body.

At that time, adopting and attaching great importance to Mulder's views in regard to proteine, he says:—'All the organic nitrogenised constituents of the body, how different soever they may be in composition, are derived from proteine. They are formed from it by the addition or subtraction of the elements of water or of oxygen, and by resolution into two or more compounds.'

He seeks to trace the changes occurring in the conversion of the constituents of food into blood, of those of blood into the various tissues, and of these into the secretions and excretions.

He states that the process of chymification takes place in virtue of a purely chemical action, exactly similar to those processes of decomposition or transformation which are known as putrefaction, fermentation, or decay. Thus, the clear gastric juice contains a substance in a state of transformation, by the contact of which with the insoluble constituents of the food they are rendered soluble, no other element taking any share in the action excepting oxygen and the elements of water. All substances which can arrest the phenomena of fermentation and putrefaction in liquids, also arrest digestion when taken into the stomach. Putrefying blood, white of egg, flesh, and cheese, produce the same effects in a solution of sugar, as yeast or ferment; the explanation being, that ferment, or yeast, is nothing but vegetable fibrine, albumen, or casein, in a state of decomposition.

Referring to the derivation of the animal tissues, he says they all contain, for a given amount of carbon, more oxygen than the nitrogenous constituents of blood. In hair and gelatinous membrane there is also an excess of nitrogen and hydrogen, and in the proportions to form ammonia. We may suppose an addition of these elements, or a subtraction of carbon, the amount of nitrogen remaining the same. The gelatinous substance is not a compound of proteine; it contains no sulphur, no phosphorus; and it contains more nitrogen, or less carbon, than proteine.

He next, as he says, attempts to develop analytically the principal metamorphoses which occur in the animal body. He adds that the results have surprised himself no less than they will others, and have excited in his own mind the same doubts as others will conceive. He nevertheless gives them, because he is convinced that the method by which they have been obtained is the only one by which we can hope to acquire an insight into the nature of organic processes.

Referring to the animal secretions, he argues that they must contain the products of the metamorphosis of the tissues. He says a starving man with severe exertion secretes more urea than the most highly fed individual in a state of rest;

and he combats the idea that the nitrogen of the food can pass into urea without having previously become part of an organised tissue.

Having shown the chemical relations of bile and urine to the proteine bodies, he illustrates, by formulæ, the connection between allantoin and the constituents of the urine of animals that respire. He insists that in the herbivora the carbohydrates must take part in the formation of bile; and he calculates the number of equivalents of proteine, starch, oxygen, and water, which would yield a given number of equivalents of urea, choleic acid, ammonia, and carbonate acid. The non-nitrogenous constituents in the food of the herbivora retard the metamorphosis of the nitrogenous bodies, rendering this less rapid than in the carnivora. It may be said that proteine, starch, and oxygen, give the secretions and excretions—carbonic acid by the lungs, urea and carbonate of ammonia by the kidneys, choleic acid by the liver. It is the study of the phenomena which accompany the metamorphoses of the food in the organism, the discovery of the share which the atmosphere and the elements of water take in these changes, by which we shall learn the conditions necessary for the production of a secretion or of an organised part.

He traces the possible formation of taurine from caffeine or asparagine by their assumption of oxygen and of the elements of water. And, from the composition of the vegetable alkaloids, he suggests the possibility of their taking a share in the formation of new, or the transformation of existing, brain and nervous matter.

Finally, in reference to these various illustrations and considerations, he says, however hypothetical they may appear, they deserve attention in so far as they point out the way which chemistry must pursue if she would really be of service to physiology and pathology. Chemistry, he says, relates to the conversion of food into the various tissues and secretions, and to their subsequent metamorphosis into lifeless compounds.

After this lapse of time, it will certainly be granted that, quite irrespectively of the admissibility or otherwise of the particular illustrations adduced, or of the truth or error of any of the conclusions drawn—and some at least are so true that they seem to us now all but truisms, and you may be disposed to ask me why I should tell you over again a story so often told before—there is no doubt that Liebig's manner of treating the subject did exert an immense influence, by stimulating investigation, by fixing attention on the points to be investigated, and on the methods that must be followed, and thus, by leading to the establishment or the correction of any special views he put forward, and to a vast extension of our knowledge on the complicated questions involved.

In the third part of Liebig's second volume he treats of the phenomena of motion in the animal organism. It is to his views in regard to one aspect only of this very wide and very complicated subject, that I propose to call your attention here, as it is chiefly in so far as that aspect is concerned that the question is of interest from the point of view of the agricultural chemist. He says:—

'We observe in animals that the conversion of food into blood, and the contact of the blood with the living tissues, are determined by a mechanical force, whose manifestation proceeds from distinct organs, and is effected by a distinct system of organs, possessing the property of communicating and extending the motion which they receive. We find the power of the animal to change its place and to produce mechanical effects by means of its limbs dependent on a second similar system of organs or apparatus.'

He points out that the motion of the animal fluids proceeds from distinct organs (as for example, that of the blood from the heart), which do not generate the force in themselves, but receive it from other parts by means of the nerves; the limbs also receive their moving force in the same way. He adds: 'Where nerves are not found, motion does not occur.' Again:—

'As an immediate effect of the manifestation of mechanical force, we see that a part of the muscular substance loses its vital properties, its character of life; that this portion separates from the living part, and loses its capacity of growth and its power of resistance. We find that this change of properties is accompanied by the entrance of a foreign body (oxygen) into the composition of the muscular fibre. . . ; and all experience proves that this conversion of living

muscular fibre into compounds destitute of vitality is accelerated or retarded according to the amount of force employed to produce motion.' He adds that a rapid transformation of muscular fibre determines a greater amount of mechanical force, and that conversely a greater amount of mechanical motion determines a more rapid change of matter.

'The change of matter, the manifestation of mechanical force, and the absorption of oxygen, are, in the animal body, so closely connected with each other that we may consider the amount of motion and the quantity of living tissue transformed as proportional to the quantity of oxygen inspired and consumed in a given time by the animal.' Again:—

'The production of heat and the change of matter are closely related to each other; but although heat can be produced in the body without any change of matter in living tissues, yet the change of matter cannot be supposed to take place without the co-operation of oxygen.'

Further, on the same point:—'The sum of force available for mechanical purposes must be equal to the sum of the vital forces of all tissues adapted to the change of matter. If, in equal times, unequal quantities of oxygen are consumed, the result is obvious in an unequal amount of heat liberated, and of mechanical force. When unequal amounts of mechanical force are expended, this determines the absorption of corresponding and unequal quantities of oxygen.'

Then, more definitely still, referring to the changes which takes place coincidentally with the exercise of force, and to the demands of the system for repair accordingly, he says:—

'The amount of azotised food necessary to restore the equilibrium between waste and supply is directly proportional to the amount of tissues metamorphosed. The amount of living matter, which in the body loses the condition of life, is, in equal temperatures, directly proportional to the mechanical effects produced in a given time. The amount of tissue metamorphosed in a given time may be measured by the quantity of nitrogen in the urine. The sum of the mechanical effects produced in two individuals, in the same temperature, is proportional to the amount of nitrogen in their urine, whether the mechanical force has been employed in the voluntary or involuntary motions, whether it has been consumed by the limbs or by the heart and other viscera.'

Thus, apparently influenced by the physiological considerations which have been adduced, and notwithstanding in some passages he seemed to recognise a connection between the total quantity of oxygen inspired and consumed and the quantity of mechanical force developed, Liebig nevertheless very prominently insisted that the amount of muscular tissue transformed—the amount of nitrogenous substance oxidated—was the measure of the force generated. He accordingly distinctly draws the conclusion that the requirement for the azotised constituents of food will be increased in proportion to the increase in the amount of force expended.

It will be obvious that the question whether in the feeding of animals for the exercise of mechanical force, that is, for their labour, the demands of the system will be proportionally the greater for an increased supply of the nitrogenous or of the non-nitrogenous constituents of food is one of considerable interest and practical importance. To this point I shall have to refer further on.

So far, I have endeavoured to convey some idea of the state of knowledge on the subject of the chemistry of agriculture prior to the appearance of Liebig's first two works bearing upon it, and also briefly to summarise the views he then enunciated in regard to some points of chief importance. Let us next try to ascertain something of the influence of his teaching.

Confining attention to agricultural research, it may be observed that in 1843—that is, very soon after the appearance of the works in question—the Royal Agricultural Society of England first appointed a consulting chemist. At that date Dr. Lyon Playfair was elected; in 1848, Professor Way; and in 1858 Dr. Voelcker, who continues to hold the office with much advantage to that union of '*Practice with Science*' which the Society by its motto recognises as so essential to progress. Also in 1843 there was established the Chemico-Agricultural Society of Scotland, which was, I believe, broken up, after it had existed between four and five years,

because its able chemist, the late Professor Johnston, failed to find a remedy for the potato disease. In 1845, the Chemico-Agricultural Society of Ulster was established, and appointed as its chemist, Professor Hodges, who still ably performs the duties of the office. Lastly, the very numerous '*Agricultural Experimental Stations*' which have been established, not only in Germany, but in most Continental States, owe their origin directly to the writings, the teachings, and the influence, of Liebig. The movement seems to have originated in Saxony, where Stöckhardt had already stimulated interest in the subject by his lectures and his writings. After some correspondence, in 1850-1, between the late Dr. Crucius and others on the one side, and the Government on the other, the first so-called *Agricultural Experimental Station* was established at Möckern, near Leipzig, in 1851-2. In 1877, the twenty-fifth anniversary of the foundation of that institution was celebrated at Leipzig, when an account (which has since been published) was given of the number of stations then existing, of the number of chemists engaged, and of the subjects which had been investigated. From that statistical statement we learn that in 1877 the number of stations was:—

In the various German States	74
In Austria	16
In Italy	10
In Sweden	7
In Denmark	1
In Russia	3
In Belgium	3
In Holland	2
In France	2
In Switzerland	3
In Spain	1
Total	122

Besides these 122 stations on the Continent of Europe, the United States are credited with 1, and Scotland also with 1.

Each of these stations is under the direction of a chemist, frequently with one or more assistants. One special duty of most of them is what is called manure- or seed- or feeding-stuff-control; that is, to examine or analyse, and report upon, such substances in the market; and it seems to have been found the interest of dealers in these commodities to submit their proceedings to a certain degree of supervision by the chemist of the station of their district.

But agricultural research has also been a characteristic feature of these institutions. It is stated that the investigation of soils has been the prominent object at 16 of them; experiments with manures at 24; vegetable physiology at 28; animal physiology and feeding experiments at 20; vine culture and wine-making at 13; forest culture at 9; and milk-production at 11. Others, according to their locality, have devoted special attention to fruit culture, olive culture, the cultivation of moor, bog, and peat land, the production of silk, the manufacture of spirit, and other products.

Nor does this enumeration of the institutions established as the direct result of Liebig's influence, and of the subjects investigated under their auspices, complete the list either of the workers engaged, or of the work accomplished in agricultural research. To say nothing of the labours of Boussingault, which commenced some years prior to the appearance of Liebig's first work, and which are fortunately still at the service of agriculture, important contributions have been made by the late Professors Johnston and Anderson in Scotland, and in this country both by Mr. Way and Dr. Voelcker, each alike in his private capacity, and in fulfilment of his duties as Chemist to the Royal Agricultural Society of England. Nor would it be fair to Mr. Lawes (who commenced experimenting first with plants in pots, and afterwards in the field, soon after entering into possession of his property in 1834, and with whom I have myself been associated since 1843), were I to omit in this place any mention of the investigations which have been so many years in progress at Rothamsted

So much for the machinery; but what of the results achieved by all this activity in the application of chemistry to agriculture?

As I have already intimated, and as the foregoing brief statistical statement will have convinced you must be the case, it will be utterly impossible to give, on such an occasion as this, anything approaching to an adequate review of the progress achieved. Indeed, I have to confess that the more I have looked at the subject with the hope of treating it comprehensively, the more I have been impelled to substitute a very limited plan for the much more extended scheme which I had at first hoped to be able to fill up. I propose then to confine attention to a few special points, which have either some connection with one another, or to which recent results or discussions lend some special interest.

First as to the sources and the assimilation of the carbon, the hydrogen, and the oxygen of vegetation. From the point of view of the agricultural chemist, the hydrogen and the oxygen may be left out of view. For, if the cultivator provide to the plant the conditions for the accumulation of sufficient nitrogen and carbon, he may leave it to take care of itself in the matter of hydrogen and oxygen. That the hydrogen of the carbo-hydrates is exclusively obtained from water, is, to say the least, probable; and whether part of their oxygen is derived from carbonic acid, and part from water, or the whole from either of these, will not affect his agricultural practice.

With regard to the carbon, the whole tendency of subsequent observations is to confirm the opinion put forward by De Saussure about the commencement of the century, and so forcibly insisted upon by Liebig forty years later—that the greater part, if not the whole of it, is derived from the carbonic acid of the atmosphere. Indeed, direct experiments are not wanting—those of Moll, for example—from which it has been concluded that plants do not even utilise the carbonic acid which they may take up from the soil by their roots. However this may be, we may safely conclude that practically the whole of the carbon which it is the object of the cultivator to force the plants he grows to take up is derived from the atmosphere, in which it exists in such extremely small proportion, but nevertheless large actual, and constantly renewed amount.

Judging from the more recent researches on the point, it would seem probable that the estimate of one part of carbon, as carbonic acid, in 10,000 of air, is more probably too high than too low as an estimate of the average quantity in the ambient atmosphere of our globe. And, although this would correspond to several times more in the column of air resting over an acre of land than the vegetation of that area can annually take up, it represents an extremely small amount at any one time in contact with the growing plants, and it could only suffice on the supposition of a very rapid renewal, accomplished as the result, on the one hand of a constant return of carbonic acid to the atmosphere by combustion and the respiration of animals, and on the other of a constant interchange and equalisation among the constituents of the atmosphere.

It will convey a more definite idea of what is accomplished by vegetation in the assimilation of carbon from the atmosphere if I give, in round numbers, the results of some direct experiments made at Rothamsted, instead of making general statements merely.

In a field which has now grown wheat for thirty-seven years in succession, there are some plots to which not an ounce of carbon has been returned during the whole of that period. Yet, with purely mineral manure, an average of about 1,000 pounds of carbon is annually removed from the land; and where a given amount of nitrogenous manure is employed with the mineral manure, an average of about 1,500 pounds per acre per annum more is obtained; in all an average of about 2,500 pounds of carbon annually assimilated over an acre of land without any return of carbonaceous manure to it.

In a field in which barley has been grown for twenty-nine years in succession, quite accordant results have been obtained. There, smaller amounts of nitrogenous manure have been employed with the mineral manure than in the experiments with wheat above cited; but the increase in the assimilation of carbon for a given amount of nitrogen supplied in the manure is greater in the case of the barley than of the wheat.

With sugar-beet, again, larger amounts of carbon have been annually accumulated without the supply of any to the soil, but under the influence of a liberal provision of both nitrogenous and mineral manure, than by either wheat or barley.

Lastly, with grass, still larger amounts of carbon have been annually accumulated, without any supply of it by manure.

Many experiments have been made, in Germany and elsewhere, to determine the amount of the different constituents taken up at different periods of the growth of various plants. But we may refer to some made at Rothamsted long ago to illustrate the rapidity with which the carbon of our crops may be withdrawn from the atmosphere.

In 1847, we carefully took samples from a growing wheat crop at different stages of its progress, commencing on June 21, and in these samples the dry matter, the mineral matter, the nitrogen, &c., were determined. On each occasion the produce of two separate eighths or sixteenths of an acre was cut and weighed, so that the data were provided to calculate the amounts of the several constituents which had been accumulated per acre at each period. The result was that, whilst during little more than five weeks from June 21, there was comparatively little increase in the amount of nitrogen accumulated over a given area, more than half the total carbon of the crop was accumulated during that period.

Numerous experiments of a somewhat similar kind, made in another season, 1856, concurred in showing that, whilst the carbon of the crop was more than doubled after the middle of June, its nitrogen increased in a much less degree over the same period.

Similar experiments were also made, in 1854 and in 1856, with beans. The general result was that a smaller proportion of both the total nitrogen and the total carbon was accumulated by the middle or end of June than in the case of the wheat; though the actual amount of nitrogen taken up by the beans was much greater, both before and after that date. The nitrogen of this leguminous crop increased in a much greater proportion during the subsequent stages of growth than did that of the gramineous crop; but the carbon increased in a larger proportion still, three-fourths or more of the total amount of it being accumulated after the middle of June.

I should say that determinations of carbon, made in samples of soil taken from the wheat field at different periods during recent years, indicate some decline in the percentage of carbon in the soils, but not such as to lead to the supposition that the soils have contributed to the carbon of the crops. Besides the amount of carbon annually removed, there will, of course, be a further accumulation in the stubble and roots of the crops; and the reduction in the total carbon of the soil, if such have really taken place, would show that the annual oxidation within it is greater than the annual gain by the residue of the crops.

Large as is the annual accumulation of carbon from the atmosphere over a given area in the cases cited, it is obvious that the quantity must vary exceedingly with variation of climatal conditions. It is, in fact, several times as great in the case of tropical vegetation—that of the sugar-cane for example. And not only is the greater part of the assimilation accomplished within a comparatively small portion of the year (varying of course according to the region), but the action is limited to the hours of daylight, whilst during darkness there is rather loss than gain.

But it is remarkable that whilst the accumulation of carbon, the chief gain of solid material, takes place under the influence of light, cell-division, cell-multiplication, increase in the structure of the plant, in other words, what, as distinguished from assimilation, vegetable physiologists designate as *growth*, takes place, at any rate chiefly, during the night; and is accompanied, not with the taking up of carbonic acid and the yielding up of oxygen, but with the taking up of oxygen and the giving up of carbonic acid. This evolution of carbonic acid during darkness must obviously be extremely small, compared with the converse action during daylight, coincidentally with which practically the whole of the accumulation of solid substance is accomplished. But, as the product of the night action is the same as in the respiration of animals, this is distinguished by vegetable physiologists as the respiration of plants.

I suppose I shall be considered a heretic if I venture to suggest that it seems in a

sense inappropriate to apply the term *growth* to that which is associated with actual loss of material, and that the term *respiration* should be applied to so secondary an action as that as the result of which carbonic acid is given off from the plant. It may, I think, be a question whether there is any advantage in thus attempting to establish a parallelism between animal and vegetable processes; rather would it seem advantageous to keep prominently in view their contrasted, or at any rate complementary characteristics, especially in the matter of the taking up of carbonic acid and the giving up of oxygen on the one hand, and the taking in of oxygen and the giving up of carbonic acid on the other.

But it is obvious that in latitudes where there is comparatively continuous daylight during the periods of vegetation, the two actions—designated respectively assimilation and growth—must go on much more simultaneously than where there is a more marked alteration of daylight and darkness. In parts of Norway and Sweden, for example, where, during the summer, there is almost continuous daylight, crops of barley are grown with only from six to eight weeks intervening from seed-time to harvest. And Professor Schübeler, of Christiania, after making observations on the subject for nearly thirty years, has recently described the characteristics of the vegetation developed under the influence of short summers with almost continuous light. He states that, after acclimatisation, many garden flowers increase in size and depth of colour; that there is a prevailing tinge of red in the plants of the fields; that the aroma of fruits is increased, and their colour well developed, but that they are deficient in sweetness; and that the development of essential oils in certain plants is greater than in the same plants grown in other latitudes. Indeed, he considers it to be an established fact that light bears the same relation to aroma as heat does to sweetness.

In connection with this question of the characters of growth under the influence of continuous light, compared with those developed with alternate light and darkness, the recent experiments of Dr. Siemens on the influence of electric light on vegetation are of considerable interest.

In one series of experiments, he kept one set of plants entirely in the dark, a second he exposed to electric light only, a third to daylight only, and a fourth to daylight, and afterwards to electric light from 5 to 11 P.M. Those kept in the dark acquired a pale yellow colour, and died; those exposed to electric light only, maintained a light green colour, and survived; those exposed to daylight were of a darker green colour, and were more vigorous; and, lastly, those submitted to alternate daylight and electric light, and but a few hours of darkness, showed decidedly greater vigour, and, as he says, the green of the leaf was of a dark rich hue. He concluded that daylight was twice as effective as electric light; but that, nevertheless, 'electric light was clearly sufficiently powerful to form chlorophyll and its derivatives in the plants.'

In a second series of experiments one group of plants was exposed to daylight alone; a second to electric light during eleven hours of the night, and was kept in the dark during the day; and a third to eleven hours day, and eleven hours electric light. The plants in daylight showed the usual healthy appearance; those in alternate electric light and darkness were for the most part of a lighter colour; and those in alternate daylight and electric light far surpassed the others in darkness of green and vigorous appearance generally.

I have carefully considered these general descriptions with a view to their bearing on the question whether the characters developed under the influence of electric light, and especially those under the influence of almost continuous light, are more prominently those of assimilation or of growth; but I have not been able to come to a decisive opinion on the point. From some conversation I had with Dr. Siemens on the subject, I gather that the characteristics were more those of dark colour and vigour than of tendency to great extension in size. The dark green colour we may suppose to indicate a liberal production of chlorophyll; but if the depth of colour was more than normal, it might be concluded that the chlorophyll had not performed its due amount of assimilation work. In regard to this point, attention may be called to the fact that Dr. Siemens refers to the abundance of the blue or actinic rays in the electric arc, conditions which would not be supposed

specially to favour assimilation. On the other hand, the vigour, rather than characteristic extension in size, would seem to indicate a limitation of what is technically called growth, under the influence of the almost continuous light.

Among the numerous field experiments made at Rothamsted, we have many examples of great variation in depth of green colour of the vegetation growing on plots side by side under known differences as to manuring; and we have abundant evidence of difference of composition, and of rate of carbon-assimilation, coincidently with these different shades of colour. One or two instances will strikingly illustrate the point under consideration.

There are two plots side by side in the series of experiments on permanent grass land, each of which received during six consecutive years precisely the same amount of a mixed mineral manure, including potass, and the same amount of nitrogen in the form of ammonia salts. After those six years, one of the two plots was still manured in exactly the same way each year; whilst the other was so, with one exception—namely, the potass was now excluded from the manure. Calculation shows that there was a great excess of potass applied during the first six years; and there was no marked diminution of produce during the five or six years succeeding the cessation of the application. But each year subsequently, up to the present time, now a period of fourteen years, or of nineteen since the exclusion of the potass, the falling off in produce has been very great.

The point of special interest is, however, that all but identically the same amount of nitrogen has been taken up by the herbage growing with the deficiency of potass as by that with the continued supply of it. The colour of the vegetation with the deficiency of potass has been very much darker green than that with the full supply of it. Nevertheless, taking the average of the eight years succeeding the first six of the exclusion of the potass, there has been nearly 400 lbs. less carbon assimilated per acre per annum; and in some of the still later years the deficiency has been very much greater than this.

We have here, then, the significant fact that an equal amount of nitrogen was taken up in both cases, that chlorophyll was abundantly produced, but that the full amount of carbon was not assimilated. In other words, the nitrogen was there, the chlorophyll was there, there was the same sunlight for both plots; but the assimilation-work was not done where there was not a due supply of potass.

Again, in the field in which barley has now been grown for twenty-nine years in succession, there are two plots which have annually received the same amount of nitrogen—the one in conjunction with salts of potass, soda, and magnesia; and the other with the same, and superphosphate of lime in addition. The plot without the superphosphate of lime always maintains a darker green colour. At any given period of growth the dry substance of the produce would undoubtedly contain a higher percentage of nitrogen; but there has been a deficient assimilation of carbon, amounting to more than 500 lbs. per acre per annum, over a period of twenty-eight years. Here again, then, the nitrogen was there, the chlorophyll was there, the sunlight was there, but the work was not done.

It may be stated generally that, in comparable cases, depth of green colour, if not beyond a certain limit, may be taken to indicate corresponding activity of carbon assimilation; but the two instances cited are sufficient to show that we may, so far as the nitrogen, the chlorophyll, and the light are concerned, have the necessary conditions for full assimilation, but not corresponding actual assimilation.

It cannot, I think, fail to be recognised that in these considerations we have opened up to view a very wide field of research, and some of the points involved we may hope will receive elucidation from the further prosecution of Dr. Siemens's experiments. He will himself, I am sure, be the first to admit that what he has already accomplished has done more in raising than in settling important questions. I understand that he proposes to submit plants to the action of the separated rays of his artificial light, and the results obtained cannot fail to be of much interest. But it is obvious that the investigation should now pass from its present initiative character to that of a strictly quantitative enquiry. We ought to know not only that, under given conditions as to light, plants acquire a deeper green colour and attain maturity much earlier than under others, but how much matter is assimilated.

lated in each case, and something also of the comparative chemical characters of the products. As between the action of one description of light and another, and as between the greater or less continuity of exposure, we ought to be able to form a judgment whether the proper balance between assimilation on the one hand, and growth and proper maturation on the other, has been attained; whether the plants have taken up nitrogen and mineral matter, and produced chlorophyll, in a greater degree than the quantity and the quality of the light have been able to turn to account; or whether the conditions as to light have been such that the processes of transformation and growth from the reserve material provided by assimilation have not been normal, or have not kept pace with the production of that material.

But one word more in reference to Dr. Siemens's results and proposed extension of his enquiries. Even supposing that by submitting growing crops to continuous light by the aid of the electric light during the night, they could be brought to maturity within a period shorter than at present approximately in proportion to the increased number of hours of exposure, the estimates of the cost of illuminating the vegetation of an acre of land certainly do not seem to hold out any hope that agriculture is likely to derive benefit from such an application of science to its needs. If, however, the characters of growth and of maturation should prove to be suitable for the requirements of horticultural products of luxury and high value, it may possibly be otherwise with such productions.

The above considerations obviously suggest the question: What is the office of chlorophyll in the processes of vegetation? Is it, as has generally been assumed, confined to effecting, in some way not yet clearly understood, carbon assimilation, and, this done, its function ended? Or is it, as Pringsheim has recently suggested, chiefly of avail in protecting the subjacent cells and their contents from those rays of light which would be adverse to the secondary processes which have been distinguished as growth?

Appropriate as it would seem that I should attempt to lay before you a *résumé* of results bearing upon the points herein involved, so numerous and so varied have been the investigations which have been undertaken on the several branches of the question in recent years, that adequately to discuss them would occupy the whole time and space at my disposal. I must therefore be content thus to direct attention to the subject and pass on to other points.

It has been shown that the plant may receive abundance of nitrogen, may produce abundance of chlorophyll, and may be subject to the influence of sufficient light, and yet not assimilate a due amount of carbon. On the other hand, it has been seen that the mineral constituents may be liberally provided, and yet, in the absence of a sufficient supply of nitrogen in an available condition, the deficiency in the assimilation of carbon will be still greater. In fact, assuming all the other necessary conditions to be provided, it was seen that the amount of carbon assimilated depended on the available supply of nitrogen.

In a certain general sense it may be said that the success of the cultivator may be measured by the amount of carbon he succeeds in accumulating in his crops. And as, other conditions being provided, the amount of carbon assimilated depends on the supply of nitrogen in an available form within the reach of the plants, it is obvious that the question of the sources of the nitrogen of vegetation is one of first importance. Are they the same for all descriptions of plants? Are they to be sought entirely in the soil, or entirely in the atmosphere, or partly in the one and partly in the other?

These are questions which Mr. Lawes and myself have discussed so frequently that it might seem some apology was due for recurring to the subject here, especially as I referred to it in some of its aspects before this Section at the Sheffield Meeting last year. But the subject still remains one of first importance to agriculture, and it could not be omitted from consideration in such a review as I have undertaken to give. Moreover, there are some points connected with it still unsettled, and some still disputed.

It will be remembered that De Saussure's conclusion was that plants did not assimilate the free or uncombined nitrogen of the atmosphere, and that they

derived their nitrogen from the compounds of it existing in the atmosphere, and especially in the soil. Liebig, too, concluded that plants do not assimilate nitrogen from the store of it existing in the free or uncombined state, but that ammonia was their main source, and he assumed the amount of it annually coming down in rain to be much more than we now know to be the case.

Referring to our previous papers for full details respecting most of the points in question, I will state, as briefly as I can, the main facts known—first in regard to the amount of the measurable, or as yet measured, annual deposition of combined nitrogen from the atmosphere; and secondly as to the amount of nitrogen annually assimilated over a given area by different crops—so that some judgment may be formed as to whether the measured atmospheric sources are sufficient for the requirements of agricultural production, or whether, or where, we must look for other supplies?

First, as to the amount of combined nitrogen coming down as ammonia and nitric acid in the measured aqueous deposits from the atmosphere.

Judging from the results of determinations made many years ago, partly by Mr. Way, and partly by ourselves, in the rain, &c., collected at Rothamsted; from the results of numerous determinations made much more recently by Professor Frankland in the deposits collected at Rothamsted, and also in rain collected elsewhere; from the results obtained by Boussingault in Alsace; from those of Marié-Davy at the Meteorological Observatory at Montsouris, Paris; and from those of many others made in France and Germany—we concluded, some years ago, that the amount of combined nitrogen annually so coming down from the atmosphere would not exceed 8 or 10 lbs. per acre per annum in the open country in Western Europe. Subsequent records would lead to the conclusion that this estimate is more probably too high than too low. And here it may be mentioned in passing, that numerous determinations of the nitric acid in the drainage water collected from land at Rothamsted, which had been many years unmanured, indicate that there may be a considerable annual loss by the soil in that way; indeed, probably sometimes much more than the amount estimated to be annually available from the measured aqueous deposits from the atmosphere.

It should be observed, however, that the amount of combined nitrogen, especially of ammonia, is very much greater in a given volume of the minor aqueous deposits than it is in rain; and there can be no doubt that there would be more deposited within the pores of a given area of soil than on an equal area of the non-porous even surface of a rain-gauge. How much, however, might thus be available beyond that determined in the collected and measured aqueous deposits, the existing evidence does not afford the means of estimating with any certainty.

The next point to consider is—What is the amount of nitrogen annually obtained over a given area, in different crops, when they are grown without any supply of it in manure? The field experiments at Rothamsted supply important data relating to this subject.

Thus, over a period of 32 years (up to 1875 inclusive), wheat yielded an average of 20·7 lbs. of nitrogen per acre per annum, without any manure; but the annual yield has declined from an average of more than 25 lbs. over the first 8, to less than 16 lbs. over the last 12, of those 32 years; and the yield (it is true with several bad seasons), has been still less since.

Over a period of 24 years, barley yielded 18·3 lbs. of nitrogen per acre per annum, without any manure; with a decline from 22 lbs. over the first 12, to only 14·6 lbs. over the next 12 years.

With neither wheat nor barley did a complex mineral manure at all materially increase the yield of nitrogen in the crops.

A succession of so-called 'root crops'—common turnips, Swedish turnips, and sugar beet (with 3 years of barley intervening after the first 8 years)—yielded, with a complex mineral manure, an average of 26·8 lbs. of nitrogen per acre per annum over a period of 31 years. The yield declined from an average of 42 lbs. over the first 8 years, to only 13·1 lbs. (in sugar beet) over the last 5 of the 31 years; but it has risen somewhat during the subsequent 4 years, with a change of crop to mangolds.

With the leguminous crop, beans, there was obtained, over a period of 24 years, 31.3 lbs. of nitrogen per acre per annum without any manure, and 45.5 lbs. with a complex mineral manure, including potash (but without nitrogen). Without manure the yield declined from 48.1 lbs. over the first 12 years to only 14.6 lbs. over the last 12; and with the complex mineral manure it declined from 61.5 lbs. over the first 12, to 29.5 lbs. over the last 12, years of the 24.

Again, an ordinary rotation of crops—of turnips, barley, clover or beans, and wheat—gave over a period of 28 years an average of 36.8 lbs. of nitrogen per acre per annum without any manure, and of 45.2 lbs. with superphosphate of lime alone, applied once every four years, that is for the root crop. Both without manure, and with superphosphate of lime alone, there was a considerable decline in the later courses.

A very remarkable instance of nitrogen yield is the following—in which the results obtained when barley succeeds barley, that is when one gramineous crop succeeds another, are contrasted with those when a leguminous crop, clover, intervenes between the two cereal crops. Thus, after the growth of six grain crops in succession by artificial manures alone, the field so treated was divided, and, in 1873, on one half barley, and on the other half clover, was grown. The barley yielded 37.3 lbs. of nitrogen per acre, but the three cuttings of clover yielded 151.3 lbs. In the next year, 1874, barley succeeded on both the barley and the clover portions of the field. Where barley had previously been grown, and had yielded 37.3 lbs. of nitrogen per acre, it now yielded 39.1 lbs.; but where the clover had previously been grown, and had yielded 151.3 lbs. of nitrogen, the barley succeeding it gave 69.4 lbs., or 30.3 lbs. more after the removal of 151.3 lbs. in clover, than after the removal of only 37.3 lbs. in barley.

Nor was this curious result in any way accidental. It is quite consistent with agricultural experience that the growth and removal of a highly nitrogenous leguminous crop should leave the land in high condition for the growth of a gramineous corn crop, which characteristically requires nitrogenous manuring; and the determinations of nitrogen in numerous samples of the soil taken from the two separate portions of the field, after the removal of the barley, and the clover, respectively, concurred in showing considerably more nitrogen, especially in the first 9 inches of depth, in the samples from the portion where the clover had been grown, than in those from the portion whence the barley had been taken. Here, then, the surface soil, at any rate, had been considerably enriched in nitrogen by the growth and removal of a very highly nitrogenous crop.

Lastly, clover has now been grown for twenty-seven years in succession, on a small plot of garden ground which had been under ordinary garden cultivation for probably two or three centuries. In the fourth year after the commencement of the experiment, the soil was found to contain, in its upper layers, about four times as much nitrogen as the farm-arable-land surrounding it; and it would doubtless be correspondingly rich in other constituents. It is estimated that an amount of nitrogen has been removed in the clover crops grown, corresponding to an average of not far short of two hundred pounds per acre per annum; or about ten times as much as in the cereal crops, and several times as much as in any of the other crops, growing on ordinary arable land; and, although the yield continues to be very large, there has been a marked decline over the second half of the period compared with the first. Of course, calculations of the produce of a few square yards into quantities per acre can only be approximately correct. But there can at any rate be no doubt whatever that the amount of nitrogen annually removed has been very great; and very far beyond what it would be possible to attain on ordinary arable land; where, indeed, we have not succeeded in getting even a moderate growth of clover for more than a very few years in succession.

One other illustration should be given of the amounts of nitrogen removed from a given area of land by different descriptions of crop, namely, of the results obtained when plants of the gramineous, the leguminous, and other families, are growing together, as in the mixed herbage of grass-land.

It is necessary here to remind you that gramineous crops grown separately on arable land, such as wheat, barley, or oats, contain a comparatively small percentage

of nitrogen, and assimilate a comparatively small amount of it over a given area. Yet, nitrogenous manures have generally a very striking effect in increasing the growth of such crops. The highly nitrogenous leguminous crops (such as beans and clover), on the other hand, yield, as has been seen, very much more nitrogen over a given area, and yet they are by no means characteristically benefited by direct nitrogenous manuring; whilst, as has been shown, their growth is considerably increased, and they yield considerably more nitrogen over a given area, under the influence of purely mineral manures, and especially of potass manures. Bearing these facts in mind, the following results, obtained on the mixed herbage of grass land, will be seen to be quite consistent.

A plot of such mixed herbage, left entirely unmanured, gave over twenty years an average of 33 pounds of nitrogen per acre per annum. Over the same period another plot, which received annually a complex mineral manure, including potass, during the first six years, but excluding it during the last fourteen years, yielded 46·3 lbs. of nitrogen; whilst another, which received the mixed mineral manure, including potass, every year of the twenty, yielded 55·6 lbs. of nitrogen per acre per annum. Without manure, there was some decline of yield in the later years; with the partial mineral manuring there was a greater decline; but with the complete mineral manuring throughout the whole period, there was even some increase in the yield of nitrogen in the later years.

Now, the herbage growing without manure comprised about fifty species, representing about twenty natural families; that growing with the limited supply of potass comprised fewer species, but a larger amount of the produce, especially in the earlier years, consisted of leguminous species, and the yield of nitrogen was greater. Lastly, the plot receiving potass every year yielded still more leguminous herbage, and, accordingly, still more nitrogen.

The most striking points brought out by the foregoing illustrations are the following:—

First. Without nitrogenous manure, the gramineous crops annually yielded, for many years in succession, much more nitrogen over a given area than is accounted for by the amount of combined nitrogen annually coming down in the measured aqueous deposits from the atmosphere.

Second. The root crops yielded more nitrogen than the cereal crops, and the leguminous crops very much more still.

Third. In all cases—whether of cereal crops, root crops, leguminous crops, or a rotation of crops—the decline in the annual yield of nitrogen, when none was supplied, was very great.

How are these results to be explained? Whence comes the nitrogen? and especially whence comes the much larger amount taken up by plants of the leguminous and some other families, than by the gramineæ? And, lastly, what is the significance of the great decline in the yield of nitrogen in all the crops when none is supplied in the manure?

Many explanations have been offered. It has been assumed that the combined nitrogen annually coming down from the atmosphere is very much larger than we have estimated it, and that it is sufficient for all the requirements of annual growth. It has been supposed that 'broad-leaved plants' have the power of taking up nitrogen in some form from the atmosphere, in a degree, or in a manner, not possessed by the narrow-leaved gramineæ. It has been argued that, in the last stages of the decomposition of organic matter in the soil, hydrogen is evolved, and that this nascent hydrogen combines with the free nitrogen of the atmosphere, and so forms ammonia. It has been suggested that ozone may be evolved in the oxidation of organic matter in the soil, and that, uniting with free nitrogen, nitric acid would be produced. Lastly, it has by some been concluded that plants assimilate the free nitrogen of the atmosphere, and that some descriptions are able to do this in a greater degree than others.

We have discussed these various points on more than one occasion; and we have given our reasons for concluding that none of the explanations enumerated can be taken as accounting for the facts of growth.

Confining attention here to the question of the assimilation of free nitrogen by

plants, it is obvious that, if this were established, most of our difficulties would vanish. This question has been the subject of a great deal of experimental enquiry, from the time that Boussingault entered upon it, about the year 1837, nearly up to the present time. About twenty years ago it was elaborately investigated at Rothamsted. In publishing the results of that inquiry, those of others relating to it were fully discussed; and although the recorded evidence is admittedly very conflicting, we then came to the conclusion, and still adhere to it, that the balance of the direct experimental evidence on the point is decidedly against the supposition of the assimilation of free nitrogen by plants. Indeed, the strongest argument we know of in its favour, is, that some such explanation is wanted.

Not only is the balance of direct experimental evidence against the assumption that plants assimilate free or uncombined nitrogen, but it seems to us that the balance of existing indirect evidence is also in favour of another explanation of our difficulties.

I have asked what is the significance of the gradual decline of produce of all the different crops when continuously grown without nitrogenous manure? It cannot be that, in growing the same crop year after year on the same land, there is any residue left in the soil that is injurious to the subsequent growth of the same description of crop; for (excepting the beans) more of each description of crop has been grown year after year on the same land than the average yield of the country at large under ordinary rotation, and ordinary treatment—provided only, that suitable soil-conditions were supplied. Nor can the diminishing produce, and the diminishing yield of nitrogen, be accounted for on the supposition that there was a deficient supply of available mineral constituents in the soil. For, it has been shown that the cereals yielded little more, and declined nearly as much as without manure, when a complex mineral manure was used, such as was proved to be adequate when available nitrogen was also supplied. So far as the root crops are concerned, the yield of nitrogen, though it declined very much, was greater at first, and on the average, than in the case of the cereals. As to the leguminosæ, which require so much nitrogen from somewhere, it is to be observed that on ordinary arable land the yield has not been maintained under any conditions of manuring; and the decline was nearly as marked with mineral manures as without any manure. Compared with the growth of the leguminosæ on arable land, the remarkable result with the garden clover would seem clearly to indicate that the question was one of soil, and not of atmospheric supply. And the fact that all the other crops will yield full agricultural results even on ordinary arable land, when proper manures are applied, is surely very strong evidence that it is with them, too, a question of soil, and not of atmospheric supply.

But we have other evidence leading to the same conclusion. Unfortunately we have not reliable samples of the soil of the different experimental fields taken at the commencement of each series of experiments, and subsequently at stated intervals. We have, nevertheless, in some cases, evidence sufficient to show whether or not the nitrogen of the soil has suffered diminution by the continuous growth of the crop without nitrogenous manure.

Thus, we have determined the nitrogen in the soil of the continuously unmanured wheat plot at several successive periods, and the results prove that a gradual reduction in the nitrogen of the soil is going on; and, so far as we are able to form a judgment on the point, the diminution is approximately equal to the nitrogen taken out in crops; and the amount estimated to be received in the annual rainfall is approximately balanced by the amount lost by the land as nitrates in the drainage water.

In the case of the continuous root-crop soil, on which the decline in the yield of nitrogen in the crop was so marked, the percentage of nitrogen, after the experiment had been continued for twenty-seven years, was found to be lower where no nitrogen had been applied than in any other arable land on the farm which has been examined.

In the case of the experiments on the mixed herbage of grass land, the soil of the plot which, under the influence of a mixed mineral manure, including potash, had yielded such a large amount of leguminous herbage, and such a large amount of nitrogen, showed, after twenty years, a considerably lower percentage of nitrogen than that of any other plot in the series.

Lastly, determinations of nitrogen in the garden soil which has yielded so much nitrogen in clover, made in samples collected in the fourth and the twenty-sixth years of the twenty-seven of the experiments, show a very large diminution in the percentage of nitrogen. The diminution, to the depth of 9 inches only, represents approximately three-fourths as much as the amount estimated to be taken out in the clover during the intervening period; and the indication is, that there has been a considerable reduction in the lower depths also. It is to be supposed, however, that there would be loss in other ways than by the crop alone.

I would ask, Have we not in these facts—that full amounts of the different crops can be grown, provided proper soil-conditions are supplied; that without nitrogenous manure the yield of nitrogen in the crop rapidly declines; and that, coincidentally with this, there is a decline in the percentage of nitrogen in the soil—have we not in these facts, cumulative evidence pointing to the soil, rather than to the atmosphere, as the source of the nitrogen of our crops?

In reference to this point, I may mention that the ordinary arable soil at Rothamsted may be estimated to contain about 3,000 lbs. of nitrogen per acre in the first 9 inches of depth, about 1,700 lbs. in the second 9 inches, and about 1,500 lbs. in the third 9 inches—or a total of about 6,200 lbs. per acre to the depth of 27 inches.

In this connection, it is of interest to state that a sample of Oxford clay, obtained in the sub-Wealden exploration boring, at a depth of between 500 and 600 feet (and which was kindly given to me by the President of the Association, Professor Ramsay, some years ago), showed, on analysis at Rothamsted, approximately the same percentage of nitrogen as the subsoil at Rothamsted taken to the depth of about 4 feet only.

Lastly, in a letter received from Boussingault some years ago, referring to the sources whence the nitrogen of vegetation is derived, he says:—

‘From the atmosphere, because it furnishes ammonia in the form of carbonate, nitrates, or nitrites, and various kinds of dust. Theodore de Saussure was the first to demonstrate the presence of ammonia in the air, and consequently in meteoric waters. Liebig exaggerated the influence of this ammonia on vegetation, since he went so far as to deny the utility of the nitrogen which forms a part of farm-yard manure. This influence is nevertheless real, and comprised within limits which have quite recently been indicated in the remarkable investigations of M. Schlösing.

‘From the soil, which, besides furnishing the crops with mineral alkaline substances, provides them with nitrogen, by ammonia, and by nitrates, which are formed in the soil at the expense of the nitrogenous matters contained in diluvium, which is the basis of vegetable earth; compounds in which nitrogen exists in stable combination, only becoming fertilising by the effect of time. If we take into account their immensity, the deposits of the last geological periods must be considered as an inexhaustible reserve of fertilising agents. Forests, prairies, and some vineyards, have really no other manures than what are furnished by the atmosphere and by the soil. Since the basis of all cultivated land contains materials capable of giving rise to nitrogenous combinations, and to mineral substances, assimilable by plants, it is not necessary to suppose that in a system of cultivation the excess of nitrogen found in the crops is derived from the free nitrogen of the atmosphere. As for the absorption of the gaseous nitrogen of the air by vegetable earth, I am not acquainted with a single irreproachable observation that establishes it; not only does the earth not absorb gaseous nitrogen, but it gives it off, as you have observed in conjunction with Mr. Lawes, as Reiset has shown in the case of dung, as M. Schlösing and I have proved in our researches on nitrification.

‘If there is one fact perfectly demonstrated in physiology, it is this of the non-assimilation of free nitrogen by plants; and I may add by plants of an inferior order, such as mycodermis and mushrooms. (Translation).’

If, then, our soils are subject to a continual loss of nitrogen by drainage, probably in many cases more than the yeceive of combined nitrogen from the atmosphere—if the nitrogen of our crops is derived mainly from the soil, and not from the atmosphere—and if, when due return is not made from without, we are

drawing upon what may be termed the store of nitrogen of the soil itself—is there not, in the case of many soils at any rate, as much danger of the exhaustion of their available nitrogen, as there has been supposed to be of the exhaustion of their available mineral constituents?

I had hoped to say something more about soils, to advance our knowledge respecting which an immense amount of investigation has been devoted of late years, but in regard to which we have yet very much more to learn. I must, however, now turn to other matters.

I have thus far directed attention to some points of importance in connection with the sources of the constituents of our crops, and I must now briefly refer to some in connection with the composition, and to some relating to the uses, of the crops themselves.

As to composition, I must confine myself to indicating something of what is known of the condition of the nitrogen in our various crops; though I had intended to say something respecting the carbo-hydrates, and especially respecting the various members of the cellulose group.

As to the nitrogen—in our first experiments on the feeding of animals, made in 1847, 1848, and 1849, the results of which were published in the last-mentioned year—we found that, in the case of succulent roots used as food, not only were they not of value as food in proportion to their richness in nitrogen, but when the percentage of it was higher than a certain normal amount, indicating relative succulence and immaturity, they were positively injurious to the animals. So marked was the variation of result according to the condition of maturity or otherwise of the foods employed, that, when reviewing the results of the experiments which had up to that time been conducted, in a paper read before this Section of the British Association at the Belfast Meeting in 1852 (and which was published in full in the annual volume¹), we stated that the mode of estimating the amount of proteine compounds by multiplying the percentage of nitrogen by 6.3 was far from accurate, especially when applied to succulent vegetable foods, and that the individual compounds ought to be determined. The Rothamsted Laboratory staff was, however, much smaller then than it is now, and with the pressure of many other subjects upon us, it was at that time quite impossible to follow up the enquiry in that direction.

It is, indeed, only within the last ten years or so, that the question has been taken up at all systematically; but we are already indebted to E. Schulze, A. Urick, Church, Sachsse, Maercker, Kellner, Vines, Emmerling, and others, for important results relating to it.

Our knowledge in regard to the subject is, however, still very imperfect. But it is in progress of investigation from two distinctly different points of view—from that of the vegetable physiologist, and that of the agricultural chemist. The vegetable physiologist seeks to trace the changes that occur in the germination of the seed, and during the subsequent life-history of the plant, to the production of seed again. The agricultural chemist takes the various vegetable products in the condition in which they are used on the farm, or sold from it. And, as a very large proportion of what is grown, such as grass, hay, roots, tubers, and various green crops, are not matured productions, it comes to be a matter of great importance to consider whether or not any large proportion of the nitrogenous contents of such products is in such condition as not to be of avail to the animals which consume them in their food?

We cannot say that the whole of the nitrogen in the seeds with which we have to deal exists as albuminoids. But we may safely assume that the nearer they approach to perfect ripeness, the less of non-albuminoid nitrogenous matters will they contain; and, in the case of the cereal grains at any rate, it is probable that if really perfectly ripe they will contain very nearly the whole of their nitrogen as albuminoids. With regard to some leguminous and other seeds, which contain peculiar nitrogenous bodies, the range may, however, be wider.

¹ 'On the Composition of Foods, in relation to Respiration and the Feeding of Animals.'

But whatever the condition of the nitrogenous bodies in the seeds we grow or sow, with germination begins a material change. Albuminoids are transformed into peptones, or peptone-like bodies, or degraded into various amido or other compounds. Such change into more soluble and more diffusible bodies is, it is to be supposed, essential to their free migration, and to their subserviency to the purposes of growth. In the case of the germination, especially of some leguminous seeds, asparagine has been found to be a very prominent product of such degradation of the albuminoids; but it would seem that this disappears as the green parts are developed. But now the plant begins to receive supplies of nitrogen from the soil, as nitrates or ammonia, and it would seem that amides constitute a considerable proportion of the produced nitrogenous bodies, apparently as an intermediate stage in the formation of albuminoids. At any rate, such bodies are found to exist largely in the immature plant; whilst the amount of them diminishes as the plant, or its various parts, approach to maturity.

But not only have we thus, in unripened vegetable productions, a greater or less, and sometimes a very large, proportion of the nitrogenous bodies formed within the plant, existing as amido-compounds, but we may have a large amount existing in the juices as nitric acid, and some as ammonia, &c. Thus, E. Schulze determined the nitric acid in various 'roots'; and he found that, in some mangels, more than one-third of the total nitrogen existed in that form, and about one-tenth as much as ammonia. In a considerable series at Rothamsted, we have found an extremely variable proportion existing as nitric acid, according to the size, succulence, or degree of maturity, of the roots; the amount being, as a rule, the least with the ripest and less highly nitrogenous roots, and the most with the most succulent, unripe, and highly nitrogenous ones. In some cases it reached as much as from 20 to nearly 30 per cent. of the total nitrogen. In many other immature vegetable products nitric acid and ammonia have been found; but, so far as I remember, in none in anything like so large a proportion as in the so-called 'root-crops,' especially mangels. In many, however, the quantity appears to be immaterial; and it is remarkable that whilst there is so much in the 'roots,' little or none is found in potatoes.

No wonder that, in the experiments already referred to, we found the feeding result to be the worse the more succulent and immature the roots, and the higher their percentage of nitrogen, accordingly.

But it is to the difference in amount of the albuminoid bodies themselves, in different descriptions of vegetable produce, that I wish specially to direct attention, making, however, some reference to what is known of the proportion of the nitrogen existing as amido-compounds.

In some mangels E. Schulze found only from about 20 to 22 per cent. of their total nitrogen to exist as insoluble and soluble albumin. But he found in one case 32.5, and in the other 40.8 per cent. of the total nitrogen as amides. In a large series of determinations at Rothamsted, by Church's method, we found a variation of from under 20 to over 40 per cent. of the total nitrogen of mangels to exist as albuminoids; or, in other words, from nearly 60 to over 80 per cent. of it in the non-albuminoid condition.

In potatoes Schulze found from under 50 to 65 per cent. of the total nitrogen as soluble and insoluble albumin, and from 27.7 to 49.1 per cent. as neutral and acid amides. In a series of potatoes grown at Rothamsted, under very various conditions as to manuring, and in two different seasons, we found the nitrogen as albuminoids to range from little over 50 to more than 71 per cent. of the total nitrogen; leaving, of course, from less than 30 to nearly 50 per cent. to be accounted for in other ways.

Kellner determined the amount of nitrogen as albuminoids, and as amido-compounds, in a considerable series of green foods, both leguminous and gramineous, cut at different stages of their growth. The proportion of the total nitrogen not as albuminoids was, upon the whole, greater in the leguminosæ than in the graminæ. In both, however, the proportion as albuminoids increased as the plants approached to maturity. The proportion as albuminoids was in all these products very much larger than in roots, and generally larger than in potatoes. In the case of first-crop

meadow hay, we found in the separated gramineous herbage 76.4, in the leguminous herbage 82, and in the miscellaneous herbage 80.3 per cent. of the nitrogen as albuminoids; and in the second crop 86.2 per cent. in the gramineous, 88.3 per cent. in the leguminous, and 88.1 per cent. in the miscellaneous herbage. How far the higher proportion of the nitrogen as albuminoids in the second crops is to be taken as any indication of the characteristics of the autumn growth, or how far it is to be attributed to the accidental condition of the weather, may be a question.

These illustrations are sufficient to give some idea of the range and proportion of the nitrogen in different feeding crops which does not exist as albuminoids; and they are sufficient to show that a very large proportion of the non-albuminoid matter exists as various amido-compounds. The question arises, therefore, whether these bodies contribute in any way to the nutrition of the animals which feed upon them? We have but little experimental evidence on this point. As green herbage is the natural food of many descriptions of animal, we might suppose that characteristic constituents of it would not be without some value as food; but the cultivated root crops are much more artificial productions, and it is in them that we find such a very large proportion of non-albuminoid nitrogen. With respect to some of the amido-compounds, at any rate, direct experiments seem to show that they are digested in the animal body, and increase the elimination of urea. Weiske and Schrodt found that rabbits receiving, as their only nitrogenous food, either asparagine or gelatin, wasted and died; but a rabbit receiving both asparagine and gelatin increased in weight and survived to the end of the experiment, which lasted seventy-two days. From the results of other experiments made with sheep, they concluded that both asparagine and gelatin protect the albuminoids of the body from oxidation.

These considerations lead me, in conclusion, to refer briefly, and I promise it shall be as briefly as is consistent with clearness, to the two very much disputed questions of the *origin of muscular power*, and the *sources of the fat of the animal body*. These subjects Mr. Lawes and myself have frequently discussed elsewhere; but as the controversy has assumed a new phase quite recently, it seems desirable and appropriate that I should recur to it on the present occasion.

With regard to the question of the sources in the food of the fat of the animal body, Liebig originally maintained that although fat might be formed from the nitrogenous compounds within the body, the main source of it in the herbivora was the carbo-hydrates. In his later writings, he sharply criticised the experiments and arguments of those who have maintained the formation of fat chiefly from the proteine compounds; but he at the same time seems to attach more importance to that source than he formerly did. He gives it as his opinion that the question cannot be settled by experiments with herbivora. He adds that what we know with certainty is that, with these animals, albuminates and carbo-hydrates work together to produce fat; but whether the non-nitrogenous product, fat, has its origin in the albumin or in the carbo-hydrate, he considers it not easy to determine.

At the time when we commenced our experiments on the feeding of animals in 1847, the question whether the fat of the animals fed for human food was mainly derived from albuminoids or from carbo-hydrates had been scarcely raised, or at least it was not prominent. The question then was rather—whether the herbivora received their fat ready formed in their food, or whether it was produced within the body—the latter view being that which Liebig had so forcibly urged, at the same time maintaining that at any rate its chief source was the carbo-hydrates. Accordingly, our experiments were not specially arranged to determine whether or not the whole of the fat produced could or could not be derived from the albuminoids.

For each description of animal, oxen, sheep, and pigs, such foods as had been established by common experience to be appropriate were selected. The general plan of the experiments was—to give to one set a fixed amount of a recognised good food, containing known quantities of nitrogen, fatty matter, &c.; to another set the same amount of another food, of different characters in these respects; to other sets also fixed amounts of other foods in the same way; and then there was given, to the whole series, the same complementary food *ad libitum*.

Or, to one set was supplied a uniform food rich in nitrogen, and to others uniform foods poorer in nitrogen, and so on, in each case *ad libitum*.

It will be seen that, in this way, a great variety of dietaries was arranged; and it will be observed that in each case the animals themselves fixed their consumption, according to the requirements of the system.

As already indicated, the individual nitrogenous and non-nitrogenous compounds of the foods were not determined. As a rule, the constituents determined were—the total dry matter, the ash, the fatty matter, and the nitrogen; from which last the amount of nitrogenous compounds it might represent was calculated by the usual factor. But, as already intimated, the results so obtained were only used with considerable reservation, especially in the case of all immature vegetable produce. Nor was the crude fibre determined; but, as in the case of the estimated nitrogenous substance, when interpreting the results, it was always considered whether or not the food contained much or little of probably indigestible woody matter.

The animals being periodically weighed, we were thus able to calculate the amounts of the so-estimated nitrogenous substance, and of the total non-nitrogenous substance, including and excluding fat, consumed—for a given live-weight within a given time, and to produce a given amount of increase in live-weight.

Experiments were made with a large number of sheep, and a large number of pigs. And, even without making allowance for the different condition of the nitrogenous or of the non-nitrogenous constituents, in comparable foods, the results obtained uniformly indicated that both the amount consumed by a given live-weight of animal within a given time, and that required to produce a given amount of increase, were determined much more by the amount of the non-nitrogenous than by that of the nitrogenous constituents which the food supplied. And when allowance was made for the different condition of the nitrogenous constituents, and for the greater or less amount of the non-nitrogenous ones which would probably be indigestible and effete, the indications were still more remarkable and conclusive.

In very many cases the animals were slaughtered, and carefully examined as to whether the tendency of development had been more that of growth in frame and flesh, or in fatness. Here, again, the evidence was clear—that the tendency to growth in frame and flesh was favoured by a high proportion of nitrogen in the food, and that to the production of fat by a high proportion of digestible non-nitrogenous constituents.

In a few cases the actual amount of fat in the animals in the lean, and in the fat condition, was determined; and the results admitted of no doubt whatever that a very large proportion of the stored-up fat could not have been derived from the fatty matter of the food, and must have been produced within the body.

So decisive and consistent were the very numerous and very varied results in regard to these points, that we had no hesitation in concluding—not only that much of the fat stored up was produced within the body, but that the source of much, at any rate, of the produced fat must have been the non-nitrogenous constituents of the food—in other words, the *carbo-hydrates*.

As already stated, however, as the question whether the source of the produced fat was the proteine compounds or the carbo-hydrates was not then prominent, we had not so arranged the experiments as to obtain the largest possible increase in fat with the smallest possible supply of nitrogenous compounds in the food; nor did we then even calculate whether or not there was sufficient nitrogenous matter consumed to be the source of the whole of the fat produced.

This question, indeed, excited very little interest, until, at a meeting of the Congress of Agricultural Chemists held at Munich in 1865 (at which I happened to be present), Professor Voit, from the results of experiments made in Pettenkofer's respiration apparatus with dogs fed on flesh, announced his conclusion that fat must have been produced from the nitrogenous substance, and that this was probably the chief, if not the only, source of the fat, even of herbivora—an opinion which he subsequently urged much more positively.

In the discussion which followed the reading of Professor Voit's paper, Baron Liebig forcibly called in question his conclusions; maintaining not only that it was inadmissible to form conclusions on such a point in regard to herbivora,

from the results of experiments made with carnivora, but also that direct quantitative results obtained with herbivorous animals had afforded apparently conclusive evidence in favour of the opposite view.

Voit's paper excited considerable controversy, in which Mr. Lawes and myself joined. We maintained that experiments to determine such a question should be made, not with carnivora or omnivora fed on flesh, but with herbivora fed on their appropriate fattening food, and on such herbivora as common experience showed to be pre-eminently fat-producers. We pointed out¹ that the pig comprised, for a given live-weight, a comparatively small proportion of alimentary organs and contents; that, compared with that of the ruminants, his food was of a high character, yielding, for a given weight of it, much more total increase, much more fat, and much less necessarily effete matter; that, in proportion to his weight, he consumes a larger amount of food, and yields a larger amount, both of total increase and of fat, within a given time; and, lastly, that he contains a larger proportion of fat, both in a given live weight, and in his increase whilst fattening.

It is obvious that, with these characteristics, there is much less probable range of error in calculating the amount and the composition of the increase in live-weight in relation to the amount and composition of the food consumed, than in the case of the ruminants; and that, therefore, the pig is very much more appropriate for the purpose of experiments to determine the sources in its food of the fat it produces.

Accordingly, we calculated a number of our early experiments made with pigs, to determine whether or not the nitrogenous substance they consumed was sufficient for the formation of the fat they produced. For simplicity of illustration, and to give every possible advantage to the view that nitrogenous substance might have been the source of the produced fat, we assumed the whole of the crude fat of the food to have been stored up in the animal—thus estimating a minimum amount to be produced. Then, again, we supposed the whole of the nitrogenous substance of the food to be perfectly digested, and to become available for the purposes of the system. Lastly, after deducting the amount of nitrogenous substance estimated to be stored up as such, the whole of the remainder was reckoned to be so broken up that no other carbon-compounds than fat and urea would be produced.

The result was that, even adopting these inadmissible assumptions, in all the cases in which, according to common experience, the food was admittedly the most appropriate for the fattening of the animal, the calculation showed that a large amount of fat had been produced which could not have been derived from the nitrogenous substance of the food, and must, therefore, have had its source in the carbo-hydrates. Such a result is, moreover, entirely accordant with experience in practical feeding.

Reviewing the whole subject in great detail in 1869, Professor Voit refers to these results and calculations. He confesses that he has not been able to get a general view of the experiments from the mass of figures recorded, and from his comments he shows that he has on some points misunderstood them. He admits, however, that, as the figures stand, it would appear that fat had, in some instances, been derived from the carbo-hydrates. Still, he says, he cannot allow himself to consider that a transformation of carbo-hydrates into fat has thus been proved.

Professor Emil von Wolff, again, in his *Landwirthschaftliche Fütterungslehre*, referring to the same experiments, admits that they are almost incomprehensible unless we assume the direct concurrence of the carbo-hydrates in the formation of fat. He, nevertheless, seems to consider that evidence of the kind in question is inconclusive; and he suggests that experiments with pigs should be made in a respiration apparatus to determine the point.

Mr. Lawes and myself entertained, however, the utmost confidence that the question was of easy settlement without any such apparatus, provided only suitable animals and suitable foods were selected. I, accordingly, gave a paper on the subject in the *Section für Landwirthschaft-und Agricultur-Chemie*, at the *Naturforscher Versammlung* held at Hamburg in 1876.² The points which I particu-

¹ 'On the Sources of the Fat of the Animal Body,' *Phil Mag.*, December, 1866.

² The substance of that communication is given in the *Journal of Anatomy and Physiology*, vol. xi. part iv.

larly insisted upon were—that the pig should be the subject of experiment; that he should be allowed to take as much as he would eat of his most appropriate fattening food, so that his increase, and the fat he produced, should bear as large a proportion as possible to his weight, to the total food, and to the total nitrogenous substance consumed. Finally, it was maintained that, if these conditions were observed, and the constituents of the food determined, and those of the increase of the animal estimated according to recognised methods, the results could not fail to be perfectly conclusive, without the intervention, either of a respiration apparatus, or of the analysis of the solid and liquid matters voided.

Results so obtained were adduced in proof of the correctness of the conclusions arrived at. We at the same time admitted that, although, for reasons indicated, we had always assumed that fat was formed from the carbo-hydrates in the case of ruminants as well as of pigs, yet, as in our experiments with those animals we had supplied too large amounts of ready formed fat, or of nitrogenous matter, or of both, it could not be shown so conclusively by the same mode of calculation in their case as in that of pigs.

In the discussion which followed, Professor Henneberg agreed that it seemed probable that fat could be formed from the carbo-hydrates in the case of pigs. In the case of experiments with other animals, however, the amount of fat produced was too nearly balanced by the amount of fat and albuminous matters available, to afford conclusive evidence on the point.

Quite recently, Professor Emil von Wolff (*Landwirthschaftliche Jahrbücher*, Band viii. 1879, Supplement) has applied the same mode of calculation to results obtained by himself with pigs some years ago. He concluded that the whole of the body fat could not have been formed without the direct co-operation of the carbo-hydrates of the food. But what is of greater interest still is, that he also calculated, in the same way, the results of some then quite recent experiments of Henneberg, Kern, and Wattenberg, with sheep. He thus found that, even including the whole of the estimated amides with the albumin, there must have been a considerable production of fat from the carbo-hydrates; and, excluding the amides, the amount reckoned to be derived from the carbo-hydrates was of course much greater.

I will only add, on this point, that, on re-calculating some of our early results with sheep, which did not afford sufficiently conclusive evidence when the whole of the nitrogen of the food was reckoned as albumin, show a very considerable formation of fat from the carbo-hydrates, if deduction be made for the probable amount of non-albuminoid nitrogenous matter of the food.

We have now, then, the two agricultural chemists of perhaps the highest authority, both as experimenters and writers on this subject on the Continent, giving in their adhesion to the view, that the fat of the herbivora, which we feed for human food, may be, and probably is, largely produced from the carbo-hydrates. I dare say, however, that some physiologists will not change their view until Voit gives them sanction by changing his, which, so far as I know, he has not yet done.

The question which has been currently entitled that of '*The Origin of Muscular Power*,' or, '*The Sources of Muscular Power*,' has also been the subject of much investigation, and of much conflict of opinion, since the first publication of Liebig's views respecting it in 1842.

As I have already pointed out, he then maintained that the amount of muscular tissue transformed, the amount of nitrogenous substance oxidated, was the measure of the force generated in the body. He accordingly concluded that the requirement for the nitrogenous constituents of food would be increased in proportion to the increase of the force expended. In his more recent writings on the subject, he freely criticises those who take an opposite view. He nevertheless grants that the secretion of urea is not a measure of the force exerted; but, on the other hand, he does not commit himself to the admission that the oxidation of the carbo-hydrates is a source of muscular power.

The results of our own early and very numerous feeding experiments were, as has been said, extremely accordant in showing that, provided the nitrogenous constituents in the food were not below a certain rather limited amount, it was the quantity of the digestible and available non-nitrogenous constituents, and not that

of the nitrogenous substance, that determined—both *the amount consumed by a given live-weight within a given time*, and *the amount of increase in live-weight produced*. They also showed that one animal, or one set of animals, might consume two or three times as much nitrogenous substance in proportion to a given live-weight within a given time as others in precisely comparable conditions as to rest or exercise. It was further proved that they did not store up nitrogenous substance at all in proportion to the greater or less amount of it supplied in the food, but that the excess reappeared in the liquid and solid matters voided.

So striking were these results, that we were led to turn our attention to human dietaries, and also to a consideration of the management of the animal body undergoing somewhat excessive labour, as, for instance, the hunter, the racer, the cab-horse, and the foxhound, and also pugilists and runners. Stated in a very few words, the conclusion at which we arrived from these inquiries (which were summarised in our paper given at Belfast in 1852) was—that, unless the system were overtaxed, the demand induced by an increased exercise of force was more characterised by an increased requirement for the more specially respiratory, than for the nitrogenous, constituents of food.

Soon afterwards, in 1854, we found by direct experiments with two animals in exactly equal conditions as to exercise, both being in fact at rest, that the amount of urea passed by one feeding on highly nitrogenous food was more than twice as great as that fed on a food comparatively poor in nitrogen.

It was clear, therefore, that the rule which had been laid down by Liebig, and which has been assumed to be correct by so many writers, even up to the present time, did not hold good—namely, that ‘The sum of the mechanical effects produced in two individuals, in the same temperature, is proportional to the amount of nitrogen in their urine; whether the mechanical force has been employed in voluntary or involuntary motions, whether it has been consumed by the limbs or by the heart and other viscera’—unless, indeed, as has been assumed by some experimenters, there is, with increased nitrogen in the food, an increased amount of mechanical force employed in the ‘involuntary motions’ sufficient to account for the increased amount of urea voided.

The question remained in this condition until 1860, when Bischoff and Voit published the results of a long series of experiments made with a dog. They found that, even when the animal was kept at rest, the amount of urea voided varied closely in proportion to the variation in the amount of nitrogenous substance given in the food—a fact which they explained on the assumption that there must have been a corresponding increase in the force exercised in the conduct of the actions proceeding within the body itself in connection with the disposal of the increased amount of nitrogenous substance consumed. Subsequently, however, they found that the amount of urea passed by the animal was, with equal conditions as to food, &c., no greater when he was subjected to labour than when at rest; whilst, on the other hand, the carbonic acid evolved was much increased by such exercise. They accordingly somewhat modified their views.

In 1866 appeared a paper by Professors Fick and Wislicenus, giving the results obtained in a mountain ascent. They found that practically the amount of urea voided was scarcely increased by the labour thus undertaken. Professor Frankland gave an account of these experiments in a lecture at the Royal Institution in the same year; and he subsequently followed up the subject by an investigation of the heat developed in the combustion of various articles of food, applying the results in illustration of the phenomena of the exercise of force.

Lastly, Kellner has made some very interesting experiments with a horse at Hohenheim, the results of which were published last year. In one series, the experiment was divided into five periods, the same food being given throughout; but the animal accomplished different distances, and drew different weights, the draught being measured by a horse-dynamometer. The changes in live-weight, the amount of water drunk, the temperature, the amount of matters voided, and their contents in nitrogen, were also determined.

The result was, that with only moderate labour there was no marked increase

in the nitrogen eliminated in the urine, but that with excessive labour the animal lost weight and eliminated more nitrogen. Kellner concluded, accordingly, that, under certain circumstances, muscular action can increase the transformation of albumin in the organism in a direct way; but that, nevertheless, in the first line is the oxidation of the non-nitrogenous matters—carbo-hydrates and fat, next comes in requisition the circulation-albumin, and finally the organ-albumin is attacked.

In reference to these conclusions from the most recent experiments relating to the subject, we may wind up this brief historical sketch of the changes of view respecting it, with the following quotation from our own paper published in 1866: ¹—'. . . all the evidence at command tended to show that by an increased exercise of muscular power there was, with increased requirement for respirable material, probably no increased production and avoidance of urea, unless, owing to excess of nitrogenous matter in the food, or a deficiency of available non-nitrogenous substance, or diseased action, the nitrogenous constituents of the fluids or solids of the body were drawn upon in an abnormal degree for the supply of respirable material.'

In conclusion, although I fully agree with Voit, Zuntz, Wolff, and others, that there still remains much for both Chemistry and Physiology to settle in connection with these two questions of '*The Sources of the Fat of the Animal Body*' and '*The Origin of Muscular Power*,' yet I think we may congratulate ourselves on the re-establishment of the true faith in regard to them, so far at least as the most important practical points are concerned.

¹ 'Food in its relation to various exigencies of the Animal Body.—*Phil. Mag.* July, 1866.



INTRODUCTION
TO THE STUDY OF
THE SCIENTIFIC PRINCIPLES
OF
AGRICULTURE;

BEING
The Inaugural Lecture,

DELIVERED MAY 6, 1884,

AT THE UNIVERSITY MUSEUM, OXFORD,

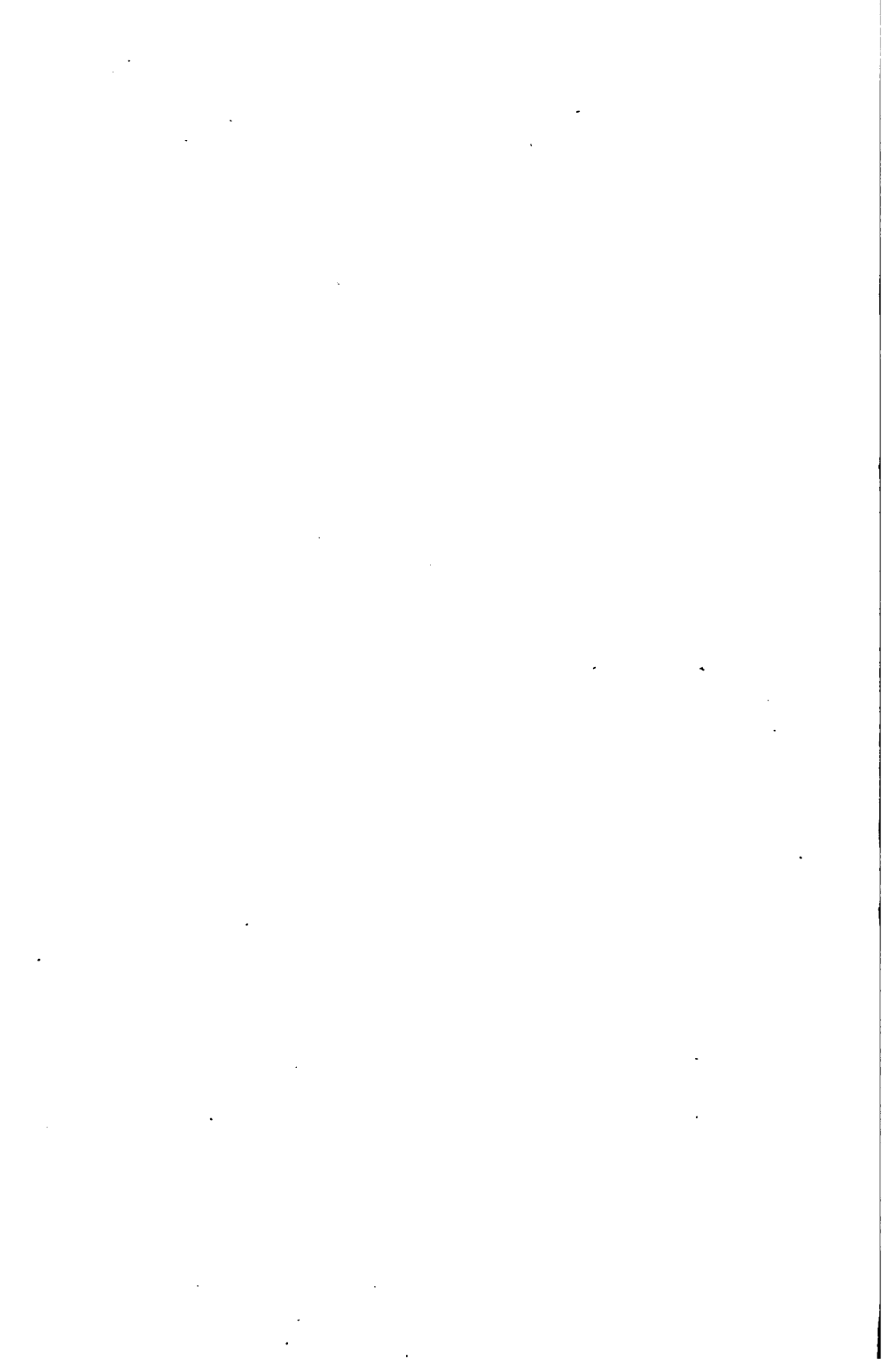
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1884.



INAUGURAL LECTURE.

OXFORD, MAY 6, 1884.

MR. VICE-CHANCELLOR AND GENTLEMEN,

THE term *Rural Economy*, which gives the title to the Professorship to which I have been appointed, might be held to include such a variety of topics, that if I had no other guide in the selection of subjects to bring before you, I should be placed in a position of some difficulty. It would not be inappropriate to treat of the general management of landed property from the point of view of the Land-owner or the Land-agent ; of the practical details of farming, mechanical, economical, and commercial, such as are essential to be observed by the tenant or occupier, if his business is to be a profitable one ; or, lastly, attention might be confined to the elucidation of the scientific principles involved in successful practice, so far as the existing knowledge of the day permitted.

Fortunately, however, I have not only the obvious intentions of the Founder of this Chair, the late Professor Sibthorp, and the way in which my Predecessor, the late Professor Daubeny, interpreted and performed the duties of the office, to guide and limit my selection of subjects ; but, on the 14th of July last, these duties were, under the sanction of the Chancery Division of the High Court of Justice, defined to be to lecture on the *Scientific Principles of Agriculture*.

It may be not out of place to remind you that, according to Dr. Sibthorp's will, the Sherardian Professor of Botany for the time being was to hold the Professorship of Rural Economy ; and that hitherto,

that is until the settlement by the Court of Chancery last year, the appointment has been so held ; and the obligation was limited to giving one Public Lecture in each term. The new arrangement, however, dissociates the Chair of Rural Economy from that of Botany, and requires that twelve lectures shall be given annually.

Thus my responsibilities are somewhat defined, and they are, at the same time, somewhat limited :—for, how far from a complete system of instruction in all that pertains to Rural Economy can be embodied in a course of twelve lectures may be judged by reference to the course of study laid down in Institutions specially devoted to the training of Students in Agriculture. Thus, the Syllabus of one Agricultural College includes no less than thirty distinct subjects of lecture or other instruction, and the Prospectus of another enumerates sixteen main departments, covering much the same range of subjects as the other ; whilst each Institution has a numerous staff of Professors or Teachers. Again, in one London College a course of forty lectures is annually given on Soils, Manures, Crops, Live Stock, &c. ; and in another lectures and laboratory instruction are given on Soils, Rotation, Manures, Feeding and Feeding-stuffs, Seeds, &c.

It is not then, I take it, expected of me that I should undertake to impart that systematic instruction in the various branches of the art and the science of Agriculture, which it is desirable the student who intends to devote himself to the details of practical farming, whether as agent or occupier, should receive. I assume that those studying at this University will for the most part be interested in land either as Owners, or as Clergymen in rural districts, or it may be as Statesmen, and that it should be my endeavour so to inculcate general principles as to train the

observation, and give a direction to the reflections, of those who hear me, and to enable, and it may be to stimulate them, to study further for themselves, as problems requiring it may come before them.

What then is Agriculture—the scientific principles of which we have to investigate? Discarding the mere etymological meaning of the term, and giving it the wider signification accorded to it by long usage, it is the art by which animal as well as vegetable products are obtained from the land.

Natural vegetation, as in the case of prairie-lands, for example, does indeed contribute food to the lower animals, and through them food and other products for the use of man; but the result is attained with little of his aid which can come under the definition of Agriculture.

But the practices by which vegetable and animal products are obtained from the land in settled countries differ essentially from those above alluded to, and it is these to which our attention must mainly be directed. Such Agriculture implies the growth of other plants than would be obtained under conditions of natural vegetation, and the growth of more produce over a given area than would be so obtained. It implies, in fact, what may be called concentrated production.

Agriculture, the oldest of the arts, was in methods at first purely mechanical; though, as we now know, the results to be attained were largely chemical. When manure was first applied to the soil, that is when the refuse of previous crops, or the excrements of animals, were first returned to the land as a means of increasing the growth of succeeding crops, directly chemical means—the supply of material—were first adopted.

Professor Daubeney, in his lectures on Roman Agriculture, quotes Cato as having said—

‘If I am asked, what is the first point in good husbandry, I answer, good ploughing ; what the second, ploughing of any kind ; what the third, manuring.’

We have thus evidence of the relatively little esteem in which manuring was held in Italy two thousand years ago ; and in the fact that so much more value was set upon the mechanical operations we have evidence that the resources of the soil itself were far from being exhausted, and only required such means to be taken to render them available.

There is nevertheless evidence that, long before the time of Cato, it was sought to restore fertility to the soil by practices the efficacy of which is still fully recognised ; though the explanation of some of the phenomena involved is still a matter of controversy. Such, for example, was the growth of various crops of the Leguminous family, sometimes to be in great part removed, but in others to be at once ploughed into the land, by either of which methods the growth of succeeding crops was enhanced. This subject will receive detailed consideration further on.

But although manuring, in various ways, has thus been so long recognised as desirable, it is in fact only in quite recent times that the rationale of such practices could be at all satisfactorily explained. To this end it was obviously essential not only to know the composition of the vegetable products grown, but something of the sources of their various constituents—whether these must be derived from the soil, or whether from the atmosphere, or from water ?

What then is the composition, and what are the sources of the constituents of vegetable products ?

When a vegetable (or animal) substance is burnt,

the greater part of it is dissipated, but there remains a white ash. This ash is found on analysis to contain most or all of the constituents enumerated in the first column of the following Table.

Constituents of Plants and Animals.

INCOMBUSTIBLE OR FIXED.	COMBUSTIBLE OR VOLATILE.
Iron. (Manganese). Lime. Magnesia. Potash. Soda. Phosphoric acid. Sulphuric acid. Chlorine. Silica.	Carbon. Hydrogen. Oxygen. Nitrogen.
Sulphur. Phosphorus.	

Rarer substances than these are also sometimes found. It will be my duty, in subsequent lectures, to call your attention in some detail to what is known as to the occurrence, and the offices, of the various mineral or ash-constituents in plants. It will suffice here to say, that the ash of one and the same description of plant, growing on different soils, may, so long as it is in the vegetative or immature state, differ very much in composition. Again, the ashes of different species, but growing on the same soil, will differ very widely in the proportion of their several constituents. But it is found that the nearer we approach to the elaboration of the final products of the plant—the seed for example—the more fixed is the composition of the ash of such products of one and the same species. In other words, there is very

little variation in the composition of the ash of one and the same description of seed, or other final product, provided it be evenly and perfectly matured. This fact alone, independently of what has been established of late years in regard to the office or function so to speak of individual mineral constituents of plants, would be sufficient to indicate the essentialness of such constituents for healthy growth.

Th. De Saussure, in his work entitled, '*Recherches sur la Végétation*,' published in 1804, gave the results of the analyses of many plant-ashes, maintained the essentialness of the ash-constituents, and pointed out that they must be derived from the soil. He also called attention to the probability that the incombustible constituents so derived by plants from the soil were the source of those found in the animals which fed upon them.

Yet such was the prevailing uncertainty on the point, that Sir Humphrey Davy, in his lectures delivered not long afterwards, deemed it not inappropriate to combat the idea that the earths found in plants had been formed from any of the elements existing in the air, or in water. After quoting the results of an experiment of his own, in which he attempted to grow oats without any supply of silica beyond that contained in the seed sown, and referring to the experiments of De Saussure, he says:—

'As the evidence on the subject now stands, it seems fair to conclude, that the different earths and saline substances found in the organs of plants are supplied by the soils in which they grow; and in no cases composed by new arrangements of the elements in air or water.'

It is no longer doubted that the mineral or ash-constituents of plants must be provided within the

soil, either from its own natural resources, or by means of manure. It will be seen, however, from the facts just stated, how very recently fixed ideas on the subject have been arrived at.

✓ Then, as to the combustible or volatile constituents which are expelled in the incineration—the carbon, the hydrogen, the oxygen, and the nitrogen. From what we now know of the sources of these constituents of plants, it is obvious that a knowledge of the composition of the atmosphere and of water was essential to any true conception of the main features of the vegetative process, and it was only towards the end of the last century that the composition of the air, and of water, and their mutual relations with vegetation, were first pointed out.

I shall have to go into these matters in some detail in subsequent lectures, but I would here observe that it is to the collective labours of Black, Scheele, Priestley, Lavoisier, Cavendish, and Watt, that we owe the knowledge that common air consists of nitrogen and of oxygen, with a little carbonic acid; that carbonic acid itself is composed of carbon and of oxygen; and that water is composed of hydrogen and oxygen; whilst Priestley and Ingenhousz, Sennebier and Woodhouse, investigated the mutual relations of these bodies and vegetable growth.

Thus, Priestley observed that plants possessed the faculty of purifying air vitiated by combustion, or by the respiration of animals; and he having discovered oxygen, it was found that the bubbles which Bonnet had shown to be emitted from the surface of leaves immersed in water consisted chiefly of that gas. Ingenhousz demonstrated that the action of light was essential to the development of these phenomena, and Sennebier proved that the oxygen

evolved resulted from the decomposition of the carbonic acid taken up.

So far, attention had been more prominently directed to the influence of plants upon the media with which they were surrounded, than to that of those media in contributing to the increased substance of the plants themselves.

It was, too, towards the end of the last century, and in the beginning of the present one, that De Saussure followed up these enquiries; and, in his work already alluded to, he may be said to have indicated, if not indeed established, some of the most important facts with which we are yet acquainted regarding the sources of the constituents of the growing plant. He illustrated experimentally, and even to a certain extent quantitatively, the fact that in sun-light plants increase in carbon, hydrogen, and oxygen, at the expense of carbonic acid and of water; and in his main experiment on the point he found the increase in carbon, and in the elements of water, was very closely in the proportion in which they are known to exist in the chief non-nitrogenous constituents of plants, the carbohydrates—starch, gum, sugar, cellulose, etc.

With regard to the nitrogen which plants had already been shown to contain, Priestley and Ingenhousz thought their experiments indicated that they absorbed free nitrogen from the atmosphere; but Sennebier and Woodhouse arrived at an opposite conclusion. De Saussure, again, thought that his experiments showed rather an evolution of nitrogen at the expense of the substance of the plant than any assimilation of it from gaseous media. He further concluded that the source of the nitrogen of plants was more probably the nitrogenous compounds

within the soil, and the small amount of ammonia which he demonstrated to exist in the atmosphere.

Upon the whole, De Saussure concluded that air and water contributed a much larger proportion of the dry substance of plants than did the soils in which they grew. In his view a fertile soil was one which yielded liberally to the plant nitrogenous compounds, and the incombustible or mineral constituents; whilst the carbon, hydrogen, and oxygen, of which the greater proportion of the dry substance of the plant was made up, were at least mainly derived from the air and water.

From what has been stated, it will be seen that anything like a consistent scientific explanation of vegetable and animal production was impossible until comparatively very recent times. In fact it is clear that agricultural chemistry properly so called is not a century old; whilst, without a knowledge of it, the scientific principles of agriculture could not be taught.

What then is agricultural chemistry? It is the chemistry of the soil, the chemistry of the atmosphere, the chemistry of vegetation, and the chemistry of animal life and growth, in their bearings on agricultural production.

Obviously vegetable and animal physiology are essential elements in the explanation of many of the phenomena of agricultural production; but for anything more than necessary passing reference to these branches of science you must look to the distinguished Professors of Physiology and Botany now attached to this University.

To Sir Humphrey Davy we owe the first systematic attempt to apply scientific principles to the elucidation and improvement of agricultural practice.

Each year, for ten successive years, from 1802 to 1812, he delivered a course of lectures which, in 1813, were published in a work entitled, 'Elements of Agricultural Chemistry,' which he finally revised for the fourth edition in 1827, but which has gone through several editions since.

In those lectures Sir Humphrey Davy passed in review and correlated the then existing knowledge, both practical and scientific, bearing upon agriculture. He treated of the influences of heat and light ; of the organisation of plants ; of the difference, and the change, in the chemical composition of their different parts ; of the sources, composition, and treatment of soils ; of the composition of the atmosphere, and its influence on vegetation ; of the composition and the action of manures ; of fermentation and putrefaction ; and, finally, of the principles involved in various recognised agricultural practices.

Concurrently with the delivery and the publication of Davy's Lectures in England, the most prominent writer on the scientific principles of agriculture on the continent was Thaer. In 1810 he published a work entitled 'Principes Raisonnés d'Agriculture,' and for some years afterwards contributed papers on some special points. He considered that the fertility of the soil depended on the amount and character of the humus it contained ; it being, in his view, the only substance, excepting water, that yielded aliment to plants. He pointed out that it was the residue of previous vegetation, containing carbon, hydrogen, oxygen, and nitrogen, associated with phosphorus, sulphur, and some salts. He quotes De Saussure as having shown that humus contains a lower percentage of oxygen and higher percentages of carbon and nitrogen than the plants from which it has been

produced. He states that its composition varies according to the access of oxygen and water ; that it absorbs oxygen, and gives out carbonic acid, which supplies nourishment to plants ; also, that it yields soluble extractive matter again and again by time and exposure. He further states that the more the decomposition has proceeded, the more refractory, and the less active and useful for vegetation, is the residue.

With the exception of the discourses of Sir Humphrey Davy, and the writings of Thaer, the subject seems to have received comparatively little attention, nor was any other addition of importance made to our knowledge in regard to it, during a period of more than twenty years, from the date of the appearance of De Saussure's work in 1804.

From about 1825 to 1840, Dr. Carl Sprengel, formerly Professor of Agriculture at Brunswick, published a series of about thirty papers in connection with agriculture, and agricultural chemistry. These memoirs covered a wide range of subjects, and recorded the results of numerous investigations by the author himself. Among them may be mentioned investigations on humus, humic acid, and humates ; on the constituents of some surface soils and subsoils ; on the composition of various kinds of straw, and their value as food and litter ; on the amount of potash in granites, and other rocks ; on the ash-constituents of cereal grains, &c. Lastly, he published a general treatise on manures, including a chapter on animal manures, in which he gives the results of the analysis of the solid and liquid excretions of the various animals of the farm, and, among other points, insists upon the value as manure of the ammonia yielded by such materials.

Professor Schübler, of Tübingen, also published

a Work entitled, 'Grundsätze der Agricultur-Chemie,' a second and revised edition of which was brought out in 1838, by Professor Krutzsch, of Tharand. In this Work the physical and chemical properties of soils are discussed in much detail; and the results of numerous investigations on the subject by the author himself are given.

Boussingault, who had previously published numerous papers, chiefly on chemical subjects, about 1834 became, by marriage, joint proprietor with his brother-in-law of the estate of Bechelbronn, in Alsace. His brother-in-law, M. Lebel, was both a chemical manufacturer and an intelligent practical farmer, accustomed to use the balance for the weighing of manure, crops, and cattle. Boussingault at once applied himself to Chemico-Agricultural research; and it was under these conditions of the association of 'Practice with Science' that the first laboratory on a farm was established.

From this time forward, Boussingault generally spent about half the year in Paris, and the other half in Alsace; and he has continued his scientific labours, sometimes in the city and sometimes in the country, up to the present time. I may here mention that I had the pleasure of seeing him well, and still actively interested in problems of agricultural science, at his Chateau in Alsace in the autumn of last year.

Boussingault's first important contribution to agricultural chemistry was made in 1836, when he published a paper on the amount of nitrogen in different foods, and on the equivalence of the foods, founded on the amounts of nitrogen they contained; and he compared the results so arrived at with the estimates of others founded on actual experience.

Although his conclusions on the subject have doubtless undergone modification since that time, the work itself marked a great advance on previously existing knowledge and modes of viewing the question.

In 1837 Boussingault published papers on the amount of gluten in different kinds of wheat ; on the influence of the clearing of forests on the diminution of the flow of rivers ; and on the meteorological influences affecting the culture of the vine. In 1838 he published the results of an elaborate research on the principles underlying the value of a rotation of crops. He determined by analysis the composition, organic and inorganic, of both the manures applied to the land, and the crops harvested. In his treatment of the subject he evinced a clear perception of the most important problems involved in such an enquiry ; some of which, with the united labours of himself and many other workers, have scarcely yet received an undisputed solution.

Thus, in the same year (1838), he published the results of an investigation on the question whether plants assimilate the free or uncombined nitrogen of the atmosphere ; and although the analytical methods of the day were inadequate to the decisive settlement of the point, his conclusions were in the main those which much subsequent work of his own, and much of others also, have served to confirm.

In subsequent lectures I shall have to refer in some detail to the various investigations here alluded to.

As a further element of the question of the chemical statistics of rotation, Boussingault determined the amount and composition of the residues of various crops ; also the amount of constituents consumed in the food of a cow, and of a horse, respectively, and

yielded in the milk and excretions of the cow, and in the excretions of the horse. Here, again, the exigencies of the investigation he undertook were beyond the reach of the known chemical methods of the time. Indeed, rude as the art of agriculture is generally considered to be, the scientific elucidation of its practices requires the most refined and very varied methods of research; and a characteristic of the work, not only of Boussingault, but of most agricultural investigators, may be said to be, that they have frequently had to devise methods suitable to their purpose, before they could grapple with the problems before them.

In 1839, chiefly in recognition of his important contributions to agricultural chemistry, Boussingault was elected a member of the Institute of France; and in 1878, thirty-nine years later, the Council of the Royal Society awarded to him the Copley Medal, the highest honour at their disposal, for his numerous and various contributions to science, but especially for those relating to agriculture.

The foregoing brief historical sketch is sufficient to indicate, though but in broad outline, the range of existing knowledge on the subject of agricultural chemistry prior to the appearance of Liebig's memorable work, 'Organic Chemistry in its applications to Agriculture and Physiology,' the first edition of which was published in 1840.

It will be seen that some very important, and indeed fundamental, facts had already been established in regard to vegetation; first by the numerous investigations made about half a century previously, by which the composition of the atmosphere, and of water, and the mutual relations of these and vegetable growth,

had been determined ; next by the labours of De Saussure, to which we owe a near approach to a quantitative representation of the phenomena of vegetation, which had thus far only been qualitatively observed. To De Saussure we also owe a clear perception of the importance, and of the sources, of both the nitrogen, and the ash-constituents, of plants. Then followed Davy, with the first attempt to give a systematic view of the relations of practice with science in agriculture ; Thaer, who traced the fertility of soils to the residue of previous vegetation which they contained ; Sprengel, who contributed much experimental result on various branches of the subject ; and lastly Boussingault, who had not only still further extended experimental enquiry, but brought both his own and previous results to bear upon the elucidation of long-recognised agricultural practices.

There can be no doubt that the data supplied by the researches which have been referred to, and especially those of De Saussure, Davy, Thaer, Sprengel, and Boussingault, contributed important elements to the basis of established facts upon which Liebig founded his brilliant generalisations. Indeed, so obvious was this, that, in 1841, Dumas and Boussingault published, jointly, an essay which afterwards appeared in English under the title of 'The Chemical and Physiological Balance of Organic Nature,' which was, in fact, a sort of 'réclamation.'

Nor can there be any doubt that the appearance of Liebig's two works, 'Organic Chemistry in its applications to Agriculture and Physiology' in 1840, and 'Animal Chemistry, or Organic Chemistry in its applications to Physiology and Pathology' in 1842, constituted a very marked epoch in the history of the progress of Agricultural Chemistry. In the

treatment of his subject he not only called to his aid the previously existing knowledge directly bearing upon it, but he also turned to good account the more recent triumphs of organic chemistry, many of which had been won in his own laboratory. Further, a marked feature of his expositions was the adoption of the quantitative method of illustration, and argument.

But, notwithstanding the evidence afforded by the direct experiments of De Saussure and his predecessors, Vegetable Physiologists, and some others, continued to hold the view that the humus of the soil was the source of the carbon of vegetation. Liebig gave full weight to the evidence of the experiments of De Saussure and others; he illustrated the possible or probable transformations within the plant by facts already established in organic chemistry; and he demonstrated the impossibility of the humus of the soil supplying the amount of carbon assimilated over a given area. He pointed out, that humus itself was the product of previous vegetable growth; that it could not therefore be an original source of the carbon; and that, from the degree of its insolubility, either in pure water or in water containing alkaline or earthy bases, only a small portion of the carbon assimilated by plants could be derived from the amount of humus that could possibly enter the plant in solution. He maintained that, so far as humus was beneficial to vegetation at all, it was only by its oxidation, and a consequent supply of carbonic acid within the soil; a source which he considered only of importance in the early stages of the life of a plant, and before it had developed, and exposed to the atmosphere, a sufficient amount of green surface to render it independent of soil-supplies of carbonic acid.

In subsequent lectures, evidence will be adduced showing that Liebig was certainly right, in concluding that humus is not an adequate source of the carbon of our crops. It will be seen that, to some of them at any rate, it is at most only a very limited source, if indeed it is to them a source at all. It will, on the other hand, be shown that the organic residue of previous vegetation accumulated in the soil is, to say the least, a very material source of the nitrogen of our crops.

Thus, though mistaken as to the explanation of the fertility of soils rich in humus, Thaer and others were, after all, not far from the truth when they maintained that the richness of a soil in such matter in a condition readily susceptible to oxidation, was, in a great degree, the measure of its fertility.

With regard to the hydrogen of plants, at any rate that portion of it contained in their non-nitrogenous products, Liebig maintained that its source must be water; and that the source of the oxygen was either that contained in carbonic acid, or that in water.

With regard to the nitrogen of vegetation, both from the known characters of free nitrogen, and as he considered a legitimate deduction from direct experiments, Liebig argued that plants did not assimilate uncombined nitrogen, either from the atmosphere, or dissolved in water and so absorbed by the roots. The source of the nitrogen of vegetation was, he maintained, *ammonia*; the product of the putrefaction of one generation of plants and animals affording a supply for its successors. He pointed out that, in the case of a farm receiving nothing from external sources, and selling off certain products, the amount of nitrogen in the manure produced by the consumption of some of the vegetable produce on

the farm itself, together with that due to the refuse of the crops, must always be less than was contained in the crops grown. He concluded that, although the quantity returned to the land as manure was important, a main source of the nitrogen assimilated over a given area was the ammonia brought down from the atmosphere in rain.

There can be no doubt that, owing to the limited and defective experimental evidence then at command on the point, Liebig at that time (as he did afterwards) greatly over-estimated the amount of combined nitrogen available to vegetation from that source.

In Boussingault's 'réclamation' already referred to, he gave much more prominence to the importance of the nitrogen of manures. In Liebig's next edition (in 1843) he combated the notion of the relative importance of the nitrogen of manures. He maintained, in opposition to the view put forward in his former edition, that the atmosphere afforded a sufficient supply of combined nitrogen not only for natural vegetation, but for cultivated plants; that this supply was sufficient for the cereals as well as for leguminous plants; that it was not necessary to supply nitrogen for the former; and he insisted very much more strongly than formerly, on the relative importance of the supply of the incombustible, or, as he designated them, the 'inorganic' or 'mineral,' constituents.

Many determinations of the amount of combined nitrogen brought down in rain have been made, in different countries, since the date here referred to; and in a subsequent lecture it will be shown that the amount so available to the vegetation of a given area is very much less than was assumed by Liebig, or has generally been supposed.

As to the incombustible, or, as he designated them, the '*mineral*' constituents, Liebig adduced many illustrations in proof of their essentialness. He called attention to the variation in the composition of the ash of plants grown on different soils; and he assumed a greater degree of mutual replaceability of one base by another, or of one acid by another, than could now be admitted. He traced the difference in the mineral composition of different soils to that of the rocks which had been their source; and he seems to have been led by the consideration of the gradual action of '*weathering*,' in rendering available the otherwise locked-up stores, to attribute the benefits of *fallow* exclusively to the increased supply of the incombustible or mineral constituents which would, by its agency, be brought into a condition in which they could be taken up by plants.

It will be seen further on, how very materially subsequently acquired experimental evidence has tended to modify our views as to the explanation of the benefits of *fallow*.

The benefits of an alternation of crops, Liebig considered to be in part explained by the influence of the excreted matters from one description of crop upon the growth of another. He did not attach weight to the assumption that such matters would be directly injurious to the same description of crop; but he supposed rather that the matters excreted by a plant were those which it did not need, and that they would therefore be of no avail to the same description of plant, but would be of use to others. He, however, attributed much of the benefits of a rotation, to different mineral constituents being required from the soil by the different crops.

Since the enunciation of these views, very much

direct experimental evidence bearing upon the rationale of rotation has been acquired, and it will be my duty to lay it before you in some detail.

Treating of *manure*, Liebig laid the greatest stress on the return by it of the potass and the phosphates removed by the crops. But, in his first edition, he also insisted on the importance of the nitrogen, especially that in the liquid excretions of animals, and condemned the methods of treatment of animal manures by which the ammonia was allowed to be lost by evaporation. It is curious, and significant, however, that some of the passages in that edition, in which he the most forcibly urges the value of the nitrogen of animal manures, are omitted in the third and fourth editions.

In his second work, that on *Animal Chemistry*, published in 1842, Liebig discussed two subjects of much interest and practical importance to the agriculturist:—namely, the sources in the food of the fat stored up in the animal body, and the characteristic food requirements of the animal organism induced by the exercise of force.

To render the points here at issue intelligible, it is necessary to remind you that the constituents of food, both vegetable and animal, may broadly be classed into those containing nitrogen, and those not containing it—in other words, into the nitrogenous, and the non-nitrogenous constituents.

From the nitrogenous constituents of the food, the nitrogenous constituents of the animal body—the membranes and cellular tissue, the nerves and brain, cartilage, and the organic part of bones—must be derived. It is admitted that by oxidation and transformation within the body, some of these nitro-

genous matters may yield fat, with other products, such as urea which passes off by the urine, and carbonic acid which passes off by respiration.

The non-nitrogenous constituents of the food on the other hand—the fatty matters, and the so-called carbohydrates—starch, sugar, cellulose, &c., are supposed to be the chief sources of the carbonic acid respired, and hence have sometimes been classed as the respiratory constituents of food.

The questions arise—Is the non-nitrogenous substance *fat*, which is stored up in the feeding of the herbivora, derived chiefly from the nitrogenous matters of the organs, or in the circulation, or from the non-nitrogenous matters of the food, the carbohydrates? Then, again, in the exercise of force, is the increased amount of the products of oxidation eliminated from the body chiefly due to an increased transformation of the nitrogenous substance of the tissues and fluids, or of the non-nitrogenous constituents—the fat of the body, or of the food, and the carbohydrates?

In reference to the sources of the fat of the animal body, Liebig maintained that the vegetable food consumed by herbivora did not contain anything like the amount of fat which they stored up in their bodies; and he showed how nearly the composition of fat was obtained by the simple elimination of so much oxygen, or of oxygen and a little carbonic acid, from the various carbohydrates of the vegetable food—starch, sugar, &c. Much less oxygen would be required to be eliminated from the nitrogenous constituents, such as fibrine, &c., than from a quantity of carbohydrate containing an equal amount of carbon. The formation of fatty matter in plants was of the same kind; it was the result of

a secondary action, starch being first formed from carbonic acid and water.

Referring to the exercise of force, he argued that the animal secretions must contain the products of the metamorphosis of the tissues; he concluded that a starving man, with severe exertion, would secrete more urea than the most highly fed individual in a state of rest; and he combated the idea that the nitrogen of the food can pass into urea without having previously become part of an organised tissue. He said:—

‘As an immediate effect of the manifestation of mechanical force, we see that a part of the muscular substance loses its vital properties, its character of life; that this portion separates from the living part, and loses its capacity of growth and its power of resistance. We find that this change of properties is accompanied by the entrance of a foreign body (oxygen) into the composition of the muscular fibre * * *; and all experience proves, that this conversion of living muscular fibre into compounds destitute of vitality is accelerated or retarded according to the amount of force employed to produce motion. Nay, it may safely be affirmed, that they are mutually proportional; that a rapid transformation of muscular fibre, or, as it may be called, a rapid change of matter, determines a greater amount of mechanical force; and conversely, that a greater amount of mechanical motion (of mechanical force expended in motion) determines a more rapid change of matter.’

Again:—

‘The change of matter, the manifestation of mechanical force, and the absorption of oxygen, are, in the animal body, so closely connected with each other, that we may consider the amount of motion,

and the quantity of living tissue transformed, as proportional to the quantity of oxygen inspired and consumed in a given time by the animal.'

And again:—

'The production of heat and the change of matter are closely related to each other; but although heat can be produced in the body without any change of matter in living tissues, yet the change of matter cannot be supposed to take place without the co-operation of oxygen.'

Further, on the same point:—

'The sum of force available for mechanical purposes must be equal to the sum of the vital forces of all tissues adapted to the change of matter.'

'If, in equal times, unequal quantities of oxygen are consumed, the result is obvious, in an unequal amount of heat liberated, and of mechanical force.'

'When unequal amounts of mechanical force are expended this determines the absorption of corresponding and unequal quantities of oxygen.'

Then, more definitely still, referring to the changes which take place coincidently with the exercise of force, and to the demands of the system for repair accordingly, he says:—

'The amount of azotised food necessary to restore the equilibrium between waste and supply is directly proportional to the amount of tissues metamorphosed.'

'The amount of living matter, which in the body loses the condition of life, is, in equal temperatures, directly proportional to the mechanical effects produced in a given time.'

'The amount of tissue metamorphosed in a given time may be measured by the quantity of nitrogen in the urine.'

'The sum of the mechanical effects produced in

two individuals, in the same temperature, is proportional to the amount of nitrogen in their urine; whether the mechanical force has been employed in voluntary or involuntary motions, whether it has been consumed by the limbs or by the heart and other viscera.'

Thus, apparently influenced by the physiological considerations which he had adduced, and notwithstanding that in some passages he seemed to recognise a connection between the total quantity of oxygen inspired and consumed, and the quantity of mechanical force developed, Liebig nevertheless very prominently insisted that the amount of muscular tissue transformed—the amount of nitrogenous substance oxidated—was the measure of the force generated. He accordingly draws the conclusion, that the requirement for the nitrogenous constituents of food will be increased in proportion to the increase in the amount of force expended.

It will be obvious that the question whether, in the feeding of animals for the exercise of mechanical force, that is, for their labour, the demands of the system will be proportionally the greater for the nitrogenous, or for the non-nitrogenous constituents of food, is one of considerable interest and practical importance.

In reference to this point, to that of the sources in the food of the fat of the animal body, as well as to the requirements for the different constituents of food for the maintenance, and for the general increase, of the body, in the feeding of the animals of the farm, a great deal of experimental evidence has been acquired during the last forty years, both in this country and on the Continent, and to this I shall have to refer in some detail on a future occasion.

So far, I have endeavoured to convey some idea of the state of knowledge bearing upon the scientific principles of agriculture, prior to the appearance of Liebig's first two works on the subject; and also briefly to summarise the views he then enunciated in regard to some points of chief importance. I will now attempt briefly to indicate what progress has been made since that period, largely at any rate due either to the direct influence of his teaching, or to the stimulus given to enquiry by the discussions which his writings called forth.

It is a coincidence of some interest, that the first lectures given by the Sibthorpian Professor of Rural Economy in this University, were delivered by my predecessor, the late Dr. Daubeny, almost contemporaneously with the appearance of Liebig's first Work, in 1840; one of a course of three having been given before, and two within a few months after, the publication of that work. These lectures were afterwards published, and, in his preface, Professor Daubeny expresses his indebtedness to Liebig's Work for some of the fundamental doctrines, and for some of the details embodied in his expositions.

In the lectures in question, Professor Daubeny discussed the importance of the study of botany, physiology, and chemistry, in the elucidation of agricultural practices. He contrasted the conditions of cultivation in the case of virgin soils, with those in long-settled countries. He treated of the sources of the constituents of our crops, of fallowing, manuring, and rotation, so far as the knowledge of the day permitted.

Finally, Dr. Daubeny put forward some speculations as to the origin of the constituents of the first vegetation on the surface of the globe, and

especially as to the source of the combined carbon, and the combined nitrogen, accumulated in the total existing vegetable and animal life and remains. He traced these to carbonic acid, and ammonia, evolved by volcanic action. It may be observed that one source of combined nitrogen is undoubtedly electrical action, especially in equatorial regions, but it will be seen further on, that so far as quantitative evidence is at command on the point, the amounts of combined nitrogen available from atmospheric sources over a given area, within a given time, are, at any rate in temperate latitudes, quite inadequate to account for the amounts recovered in crops over the same area, and in the same time. It will be seen too, that the question of the sources of the nitrogen of our crops, is one upon which very conflicting views are still entertained.

For a period of more than twenty-five years, Dr. Daubeney continued to give lectures from time to time on various branches of Rural Economy, generally with some reference to the discussions of the day.

But independently of discourses of this expository or critical kind, he, in 1845, described the results of some experiments he had made to elucidate the principles involved in the rotation of crops. To this end he had set apart a number of plots in the Botanic Garden, each 10 feet square. On some of these he grew the same description of plant year after year for several years in succession, whilst on others he alternated the different crops. The soil was admittedly not very favourable, being made ground, and the plots were very small. Still the results clearly showed that more produce was obtained from a given area when the different plants were grown in alternation, than when the same

description was grown successively. Subsequent examination of the soils further showed considerable differences, dependent on the exhaustion by the different crops.

Dr. Daubeny confined his illustrations and his discussions almost entirely to the mineral or ash-constituents of the crops; thus following the lines of argument current at the time. Although the facts brought out are of interest, all subsequently acquired evidence tends to show, that the benefits of rotation are not explicable by exclusive reference to the difference in the description, and amounts, of the mineral constituents which are taken up by the different crops.

Among the most notable of Professor Daubeny's lectures, was a course of eight on Roman Husbandry, which were afterwards published.

These lectures evince considerable historical research, and are of much interest independently of the facts relating to the Agriculture of the Ancients which they bring to light. But their chief interest to the agricultural student of the present day is to be found in the evidence, discernible between the lines, that certain practices then adopted for the increase of the products obtained from the land, are still recognised as effective, though, in some cases, the precise explanation of the benefits derived yet remains a matter of controversy. Thus, although no fixed rotations of crops seem to have been adopted, yet the occasional growth of plants of the Leguminous family was had recourse to, and recognised as a means of increasing the growth of the gramineous crops with which they were alternated.

Again, the evidence of both Columella and Virgil goes to show, that the fertility of soils was then attributed to the accumulations from previous natural

vegetation, and that, as this store was gradually used up, the soils became poor.

Although, as has been said, the lectures which have been given by the Sibthorpian Professor of Rural Economy commenced almost simultaneously with the appearance of Liebig's first work, and many of them had direct reference either to Liebig's own views, or to current discussions relating to them, their inauguration was prior to, and quite independent of, the interest excited by that work. Not so was it, in the case of many other agencies for promoting knowledge in regard to the scientific principles of agriculture, both in this country, and on the Continents of Europe and America. I think too, I may safely say, that the stimulus was earlier felt, and was earlier productive of results, in this country, than in Liebig's own, or elsewhere.

In 1843, the Royal Agricultural Society of England first appointed a consulting Chemist; Dr., now Sir Lyon Playfair, being the first holder of the office. In 1848, the late Professor Way was elected, and the Society's journals of that time bear testimony to his clear perception of the agricultural problems requiring solution, and of his capacity as an investigator. In 1858, Dr. Voelcker succeeded to the office, and continues to hold it with much advantage to that union of 'Practice with Science,' which the Society by its motto recognises as so essential to progress. Thus, after having been Professor of Chemistry at the Royal Agricultural College, Cirencester, for many years, Dr. Voelcker has now been consulting Chemist to the Royal Agricultural Society of England for more than a quarter of a century; and to some of the results of his investigations I shall have to refer on future occasions.

It was also in 1843, that there was established the Chemico-Agricultural Society of Scotland, which was, I believe, broken up after it had existed between four and five years, because its able Chemist, the late Professor Johnston, failed to find a remedy for the potato disease. Somewhat similar duties, including a good deal of agricultural research, have however since been performed under the auspices of the Highland and Agricultural Society of Scotland, for many years by the late Professor Anderson, and more recently by Dr. Aitken.

In 1845, the Chemico-Agricultural Society of Ulster was established; Professor Hodges was appointed as Chemist, and he continues ably to perform the duties of the office.

As already intimated, agencies of this kind were not so soon brought into operation on the Continent. Nevertheless, the numerous Agricultural Experimental Stations which have been established, not only in Germany, but in most continental States, owe their origin very directly to the writings, the teachings, and the influence of Liebig.

The movement seems to have originated in Saxony, where Stöckhardt had already stimulated interest in the subject by his lectures and his writings. After some correspondence in 1850-51, between the late Dr. Crucius and others on the one side, and the Government on the other, the first so-called 'Agricultural Experimental Station' was established at Möchern, near Leipzig, in 1851-2. In 1877 the twenty-fifth anniversary of the foundation of that Institution was celebrated at Leipzig; when an account, which has since been published, was given of the number of Stations then existing, of the number of Chemists engaged, and of the subjects which had

been investigated. From that statement we learn that at that period the number of Stations was:—

In the various German States	74
In Austria	16
In Italy	10
In Sweden	7
In Denmark	1
In Russia	3
In Belgium	3
In Holland	2
In France	2
In Switzerland	3
In Spain	1
Total	122

Thus, seven years ago there were 122 'Agricultural Stations' on the Continent of Europe, and the number has doubtless by this time considerably increased.

Each of these Stations is under the direction of a Chemist, frequently with one or more assistants. One special duty of most of them is to examine or analyse, and report upon, manures, seeds, or feeding-stuffs, offered for sale to the farmer; and it seems to have been found to be the interest of the dealers in such commodities, to submit their proceedings to a certain degree of supervision by the Chemist of the Station of their District.

But agricultural research has also been a characteristic feature of these institutions. It was stated in the report referred to, that the investigation of soils had been the prominent object at sixteen of them; experiments with manures at twenty-four; vegetable physiology at twenty-eight; animal physiology and feeding experiments at twenty; vine culture and wine making at thirteen; forest culture at nine; and milk production at eleven. Others, according to their locality, have devoted special attention to fruit culture, olive culture, the treatment of moor, bog and

peat land, the production of silk, the manufacture of spirit, and other products.

But few experimental stations having in the main similar objects to those of the Stations on the Continent of Europe, have been established either in our own Country or in America ; but in the German Report above cited, Scotland is credited with one, and the United States with one.

There are, however, several Stations in the United States, where agricultural investigation is carried on ; and a writer in that Country has recently made an appeal to the Government, to establish Stations with a view to the investigation of each general variety of soil and climate in the United States ; to assign a Chemist to each, to institute experiments with the crops most suitable to the locality, to analyse the soil, &c., and to report the results.

The records of the results of the investigations conducted at the large number of experimental stations on the Continent of Europe, are extremely voluminous ; and the number of systematic works which have appeared on various branches of the subject in the French and German languages during the last forty years is very great. I will here refer to the several editions of Liebig's first two works already alluded to, his 'Familiar Letters on Chemistry,' his 'Modern Agriculture,' his 'Principles,' and finally his 'Natural Laws of Husbandry,' all of which have appeared in the English language. Reference should also be made to Boussingault's 'Economie Rurale' the first edition of which was published in English in 1845. It has, however, gone through other editions in France ; and subsequently, at intervals from 1860 to 1878, Boussingault published a series of six volumes, entitled—'Agronomie, Chimie Agricole et

Physiologie'—and covering a still wider range of subjects, bringing the information on the various points up to date, and going into much detail as to the methods of research, as well as to the results obtained. In these volumes, those who desire it will be able to examine for themselves the evidence upon which many important conclusions have been based.

A few of the works by English authors which have appeared within the same period, it may be well to enumerate. Among them are Johnston's 'Lectures on Agricultural Chemistry and Geology,' first published in 1844; and his 'Experimental Agriculture,' published in 1849. His successor, Dr. Anderson, also published, in 1860, a work entitled—'Elements of Agricultural Chemistry.'

New editions of Johnston's work have since been published by Dr. C. Cameron; the first of these, the tenth of the original work, appearing in 1877.

Perhaps the most compendious record of the results of the Continental investigations up to the time of its publication, which has appeared in our own language, is that by Professor S. W. Johnson, of Yale College, Newhaven, Connecticut, in two volumes, entitled 'How Crops Grow,' and 'How Crops Feed.' The results of the German experiments on the Feeding of Animals have also been summarised by Dr. Armsby, in a volume published in America, and entitled—'Manual of Cattle-Feeding.'

Neither in the works above referred to, nor in the reports of the Continental Experimental Stations, do we find the record of many systematic or long continued field-experiments. We have, however, the example of Boussingault, and the opinions of Sir Humphrey Davy, Liebig, and Daubeny, as to the great importance of such methods of agricultural research.

Davy says :—

‘Nothing is more wanting in agriculture than experiments in which all the circumstances are minutely and scientifically detailed. This art will advance with rapidity in proportion as it becomes exact in its methods. As in physical researches, all the causes should be considered ; a difference in the results may be produced, even by the fall of a half-inch of rain more or less in the course of a season, or a few degrees of temperature, or even by a slight difference in the subsoil, or in the inclination of the land.’

‘Information collected after views of distinct inquiry, would necessarily be fitted for inductive reasoning, and capable of being connected with the general principles of science ; and a few histories of the results of truly philosophical experiments in agricultural chemistry would be of more value in enlightening and benefiting the farmer, than the greatest possible accumulation of imperfect trials, conducted merely in the empirical spirit.’

‘It is from the higher classes of the community, from the proprietors of land,—those who are fitted by their education, to form enlightened plans, and by their fortunes, to carry such plans into execution ; it is from these that the principles of improvement must flow to the labouring classes of the community ; and in all classes the benefit is mutual ; for the interest of the tenantry must be always likewise the interest of the proprietors of the soil.’

‘Discoveries made in the cultivation of the earth are not merely for the time and country in which they are developed, but they may be considered as extending to future ages, and as ultimately tending to benefit the whole human race ; as affording subsistence for generations yet to come ; as multiplying life ; and not

only multiplying life, but likewise providing for its enjoyment.'

Liebig said:—'I shall be happy if I succeed in attracting the attention of men of science to subjects which so well merit to engage their talents and energies. Perfect agriculture is the true foundation of all trade and industry—it is the foundation of the riches of states. But a rational system of agriculture cannot be formed without the application of scientific principles; for such a system must be based on an exact acquaintance with the means of nutrition of vegetables, and with the influence of soils and actions of manure upon them. This knowledge we must seek from chemistry, which teaches the mode of investigating the composition and of studying the characters of the different substances from which plants derive their nourishment.'

'Since the time of the immortal author of the "Agricultural Chemistry" (Davy) no chemist has occupied himself in studying the application of chemical principles to the growth of vegetables, and to organic processes. I have endeavoured to follow the path marked out by Sir Humphrey Davy, who based his conclusions only on that which was capable of inquiry and proof. This is the path of true philosophical inquiry, which promises to lead us to truth—the proper object of our research.'

The importance which Professor Daubeney attached to field-experiments, is evidenced in the facts that, at a very early period of his connection with the study and teaching of the principles of Rural Economy, he instituted the experiments on Rotation, in the Botanic Garden, already referred to; and that subsequently, I believe in 1860, he bequeathed to his successors in the Chair a piece of ground of about one and a

half acre for the purposes of experiments ; feeling, as he said in a lecture on the subject, that the objects of the foundation of the Professorship of Rural Economy—‘ would not be fully attained until the holder of it was enabled, not only to retail the information he might obtain from books, but also to illustrate it by experiment, and to verify, as well as extend the knowledge he might have derived from others through original investigations of his own.’

Briefly described, the subjects which Dr. Daubeny indicated as suitable for such enquiry were—1. To determine what amount of mechanical treatment, and what length of time, would be required to bring an exhausted soil back to fertility without manure. 2. To try whether, if a soil be rich in mineral constituents, ammoniacal manures may not be dispensed with by the use of mechanical operations ; since, as he says, Liebig’s opinion is, that many plants have the power ‘ of absorbing from the atmosphere so large an amount of ammonia, as would seem to render them independent of animal manures, and to enable them to derive all their ingredients, except their mineral ones, from the atmosphere.’ 3. The causes of the failure of clover. 4. The effects of gypsum applied as manure. 5. To try whether there is any disadvantage in the use of superphosphates from which the fluorine has been dissipated, compared with bones from which it has not. 6. Whether growing plants year after year on the same land from the seed yielded, tends to variation, or to the obliteration of specific characters. 7. Lastly, to determine how far the growth of the fungi which attack different crops may be considered as a cause, or only the effect, of disease.

I may here say that much experimental evidence

is now available with regard to some of these questions, and I shall have to call attention to it in subsequent lectures.

I may add that, very shortly after Dr. Daubeney had bequeathed the piece of ground to which I have referred, I visited it with him, and at the time expressed a fear that it was not very suitable for the objects in view, little thinking that it would fall to my lot to consider the subject more seriously, as I shall soon have to do. In the first place, I pointed out the unlevel character of the plot, and gathered from the history of it given to me, that it was very uneven as to condition. Accordingly, I suggested that, before any experiments on it were undertaken, it should be brought into an even state as far as mechanical operations could accomplish this; and that then some corn-crop should be grown for several years in succession without manure, so as, as far as possible, to obliterate the unevenness of condition arising from previous irregularity in manuring and cropping.

It will doubtless excite surprise when I say that, notwithstanding the importance of the subject, and the high authority on which the prosecution of scientifically conducted field-experiments has been advocated, the conduct of such experiments has never been an important part of the work of the Agricultural Experimental Stations on the continent of Europe, and that it is now almost excluded from their programme.

In 1880, Professor Maercker of Halle, one of the leading Agricultural Chemists of Germany, stated that belief in their value was greatly diminished, and that by some they were declared to be of no value. It is objected that the Chemists of the Agricultural Stations have neither the means nor the technical knowledge necessary for carrying out such experiments

successfully; that neither the amount of land, nor the funds at their disposal, are such as to admit of any safe deductions for application in practical agriculture from the results; and that purely physiological problems can be better investigated in the laboratory, or in the greenhouse. He remarks that, owing to the errors necessarily incident to field-experiments conducted by those not acquainted with practical agriculture, the confidence of the practical farmer in the results has been shaken. Indeed, owing to the difficulties and cost of such enquiries, if conducted in a truly scientific manner, so as to be applicable for the solution of questions of fundamental and general interest, Professor Maercker concludes that the only field-experiments which it is practicable to carry out in Germany, are such as should be conducted by the practical farmer himself, to test the applicability to practice, of results and conclusions otherwise arrived at; and that, to insure that even such experiments are not misleading, similar ones should be conducted on different descriptions of soil, and for several years in succession.

I have already quoted the opinion of Sir Humphrey Davy, that scientifically conducted field-experiments should be undertaken by proprietors of land, who by their education are fitted to form enlightened plans, and by their fortunes are able to carry them into execution; and when I tell you that the Rothamsted field-experiments, independently of all the laboratory investigations connected with them, cost considerably more, and those which have been undertaken by the Duke of Bedford at Woburn for the last seven years, on behalf of the Royal Agricultural Society of England, and which are under the direction of Dr. Voelcker, not much less, than £1000 annually, you

will not be surprised that such field-experiments are not more general.

Prior to the appearance of Liebig's first work, in 1840, Mr., now Sir John Bennet Lawes, commenced experiments with different manuring substances, first with plants in pots, and afterwards in the field, at Rothamsted, into the hereditary possession of which he had entered on his majority in 1834. The results so obtained on a small scale in 1837, 1838, and 1839, were such as to lead to more extensive trials in the field in 1840, 1841, and subsequently.

In 1843, more systematic field-experiments were commenced; and a barn, which had already been applied to laboratory purposes, became almost exclusively devoted to agricultural investigations. These, which are still in progress, have been conducted entirely at the cost of Sir John Lawes, who has further set apart a sum of £100,000, and certain areas of land, for their continuance after his death.

In June 1843, I became associated with Mr. Lawes in the conduct of these investigations; and as it is doubtless my connexion with them (which still continues), to which my election to this Chair is mainly to be attributed, it will not be out of place to give, on this occasion, a brief outline of the scope and plan of the work which has been accomplished, during the more than forty years of its continuance. That I should do so seems the more desirable, since I interpret my appointment as indicating a feeling on the part of the Electors, that the results acquired in this long period of investigation of the scientific principles of agriculture, many of which are known by their publication, must have provided important material for illustration, in the lectures which it will be my

duty to deliver. In fact, whilst I shall not neglect important results and conclusions established by others, the plan which I have in view will nevertheless involve much reliance on the data acquired at Rothamsted.

I may premise that since July 1855, when a new laboratory, built by public subscription of agriculturists, was presented to Mr. Lawes, the old barn laboratory has been abandoned. At the present time, the Rothamsted staff consists of two, and sometimes three chemists; several general assistants in different departments; occasionally a botanical assistant; three, and sometimes four, computers and record keepers; also a laboratory man, and several boys.

The general scope and plan of the field-experiments has been—to grow some of the most important crops of rotation, each separately, year after year, for many years in succession on the same land, without manure, with farmyard manure, and with a great variety of chemical manures; the same description of manure being, as a rule, applied year after year on the same plot. Experiments, with different manures on the mixed herbage of permanent grass-land, on the effects of fallow, and on an actual course of rotation, without manure, and with different manures, have likewise been made.

Field-experiments have thus been conducted for the periods, and over the areas, indicated in the table on the following page.

Samples of all the experimental crops are brought to the laboratory. Weighed portions of each are partially dried and preserved for future reference, or analysis. Duplicate weighed portions of each are dried at 100°C , the dry matter determined, and then burnt to ash. The quantities of ash are determined

Rothamsted Field Experiments.

CROPS.	DURATION.	AREA.	PLOTS.
	<i>Years.</i>	<i>Acres.</i>	
Wheat (various manures) . . .	4 ¹	13	37
Wheat, alternated with Fallow .	33	1	2
Wheat (varieties)	15	4-8	about 20
Barley (various manures) . . .	33	4 $\frac{1}{2}$	29
Oats (various manures)	10 ¹	$\frac{3}{4}$	6
Beans (various manures)	32 ²	1 $\frac{1}{2}$	10
Beans (various manures)	27 ³	1	5
Beans, alternated with Wheat . .	28 ⁴	1	10
Clover (various manures)	30 ⁵	3	18
Various Leguminous Plants . . .	7	3	17
Turnips (various manures) . . .	28 ⁶	8	40
Sugar Beet (various manures) . .	5	8	41
Mangel-Wurzel (various manures).	9	8	41
Total Root Crops	42		
Potatoes (various manures) . . .	9	2	10
Rotation (various manures) . . .	37	2 $\frac{1}{2}$	12
Permanent Grass (various manures)	29	7	22

and recorded; the ashes themselves being preserved for reference, or analysis.

In a large proportion of the samples the total nitrogen is determined; and in some the amount existing as albuminoids, amides, and nitric acid.

In selected cases, illustrating the influence of season, manures, exhaustion, &c., complete ash-analyses have been made, numbering in all more than 700.

Also in selected cases, illustrating the influence of season and manuring, quantities of the experi-

¹ Including 1 year Fallow.

² Including 1 year Wheat, and 5 years Fallow.

³ Including 4 years Fallow.

⁴ Including 2 years Fallow.

⁵ Clover, 12 times sown, 8 yielding crops, but 4 of these very small, 1 year Wheat, 5 years Barley, 12 years Fallow.

⁶ Including Barley without manure 3 years (11th, 12th, and 13th seasons).

mentally grown wheat-grain have been sent to the mill, and the proportion and composition of the different mill-products has been determined.

In the sugar-beet, mangel-wurzel, and potatoes, the sugar in the juice has in many cases been determined by polariscope, and frequently by copper also.

In the case of the experiments on the mixed herbage of permanent grass-land, besides the samples taken for the determination of the chemical composition (dry matter, ash, nitrogen, woody fibre, fatty matter, and composition of ash), carefully averaged samples have frequently been taken for the determination of the botanical composition. In this way, on four occasions, at intervals of five years—viz., in 1862, 1867, 1872, and 1877—a sample of the produce of each plot was taken, and submitted to careful botanical separation; and the percentage, by weight, of each species in the mixed herbage determined. Partial separations, in the case of samples from selected plots (frequently of both first and second crops), have also been made in other years.

Samples of the soils of most of the experimental plots have been taken from time to time, generally to the depth of 9, 18, and 27 inches; sometimes to twice, and sometimes even to four times this depth. In this way more than 1000 samples have been taken, submitted to partial mechanical separation, and portions of the fine soil (that is, excluding stones) have been carefully prepared and preserved for analysis. In a large proportion of the samples the loss on drying at different temperatures, and at ignition, has been determined. In most, the nitrogen determinable by burning with soda-lime has been estimated. In many the carbon, and in some the

nitrogen as nitric acid, and the chlorine, have been determined. Some experiments have also been made on the comparative absorptive capacity (for water and ammonia) of different soils and subsoils. The systematic investigation of the amount, and the condition, of the nitrogen, and of some of the more important mineral constituents, of the soils of the different plots, and from different depths, is now in progress, or contemplated.

Almost from the commencement of the experiments the rainfall has been measured—for more than thirty years in a gauge of one-thousandth of an acre area, as well as in an ordinary small funnel-gauge of 5 inches diameter. An 8-inch 'Board of Trade' copper-gauge is also now in use, commencing January 1, 1881. From time to time, the nitrogen as ammonia (and sometimes as nitric acid), has been determined in the rain waters. The chlorine has also been determined in many samples.

Three 'drain gauges,' also of one-thousandth of an acre each, for the determination of the quantity and composition of the water percolating, respectively through 20 inches, 40 inches, and 60 inches depth of soil (with its subsoil in natural state of consolidation), have also been constructed. Each of the differently manured plots of the permanent experimental wheat-field having a separate pipe-drain, the drainage-waters have been, and are frequently, collected and analysed.

The nitrogen existing as nitric acid, sometimes that in other forms, and also some other constituents, are, and for some time past have been, determined periodically, in both the rain and the various drainage waters.

For several years in succession, experiments were

made to determine the amount of water given off by plants during their growth. In this way various plants, including representatives of the gramineous, the leguminous, and other families, have been experimented upon. Similar experiments have also been made with various evergreen and deciduous trees.

Having regard to the difference in the character and amount of the constituents assimilated by plants of different botanical relationships, under equal external conditions, or by the same description of plants, under varying conditions, observations have been made on the character and range of the roots of different plants, and on their relative development of stem, leaf, &c. In the case of various crops, but more especially with wheat and beans, samples have been taken at different stages of growth, and the composition determined, in more or less detail, sometimes of the entire plant, and sometimes of the separated parts. In a few cases, the amounts of dry matter, ash, nitrogen, &c., in the above-ground growth of a given area, at different stages of development, have been determined. The amounts of stubble of different crops have also occasionally been estimated.

Experiments were made for several years in succession to determine whether plants assimilated free or uncombined nitrogen, and also various collateral points. Plants of the gramineous, the leguminous, and of other families, were operated upon. The late Dr. Pugh took a prominent part in this enquiry.

Obviously, an investigation of the scientific principles of Agriculture would be incomplete if it were

not extended to the question of the feeding of the animals of the farm. Accordingly, experiments with such animals were commenced early in 1847, and have been continued at intervals up to the present time.

The following points have been investigated :—

1. The amount of food, and of its several constituents, consumed in relation to a given live-weight of animal, within a given time.

2. The amount of food, and of its several constituents, consumed to produce a given amount of increase in live-weight.

3. The proportion, and relative development, of the different organs or parts of different animals.

4. The proximate and ultimate composition of the animals, in different conditions as to age and fatness, and the probable composition of their increase in live-weight during the fattening process.

5. The composition of the solid and liquid excreta (the manure), in relation to that of the food consumed.

6. The loss or expenditure of constituents by respiration and the cutaneous exhalations—that is, in the mere sustenance of the living meat—and—manure-making machine.

Several hundred animals—oxen, sheep, and pigs—have been submitted to experiment.

The amount, and the relative development, of the different organs and parts, were determined in two calves, two heifers, fourteen bullocks, one lamb, 249 sheep, and 59 pigs.

The percentages of water, mineral matter, fat, and nitrogenous substance, were determined in certain separated parts, and in the entire bodies, of ten animals—namely, one calf, two oxen, one lamb, four

sheep, and two pigs. Complete analyses of the ashes, respectively, of the entire carcasses, of the mixed internal and other 'offal' parts, and of the entire bodies, of each of these ten animals have also been made.

From the data provided, as just described, as to the chemical composition of the different descriptions of animal, in different conditions as to age and fatness, the composition of the increase whilst fattening, and the relation of the constituents stored up in increase to those consumed in food, have been estimated.

To ascertain the composition of the manure in relation to that of the food consumed, oxen, sheep, and pigs, have been experimented upon.

The loss or expenditure of constituents, by respiration and the cutaneous exhalations, has not been determined directly, but only by difference; that is, by calculation, founded on the amounts of dry matter, ash, nitrogen, &c., in the food, and in the (increase) fæces, and urine.

Independently of the points of enquiry here enumerated, the results obtained have supplied data for the consideration of the following questions:—

1. The characteristic demands of the animal body, for nitrogenous or non-nitrogenous constituents of food, in the exercise of muscular power.
2. The sources in the food of the fat produced in the animal body.
3. The comparative characters of animal and vegetable food in human dietaries.

Supplementary investigations have also been made; for example—on the application of town-sewage to different crops, including experiments on the feeding qualities of the produce grown; the amount of increase yielded by oxen, and the amount and com-

position of the milk yielded by cows, being determined.

The chemistry of the malting process, the loss of food constituents during its progress, and the comparative feeding value of barley and malt, have also been investigated.

Many of the results of the investigations above enumerated have already been published, but a large proportion as yet remains unpublished.

As already intimated, I propose to rely largely on the data supplied in the more than forty years of investigation at Rothamsted, in the field, the feeding-shed, and the laboratory, in the lectures which it will be my duty to give in this University, in elucidation of the scientific principles of agriculture.

In the first place, however, to give logical sequence to what will follow, I shall devote a few lectures to the question of the sources of the constituents of the plants and animals which are the products of the art of agriculture. Obviously, the soil, and the atmosphere, are these sources. The subject of the origin, the general characters, and the composition, of soils, is a very wide one; and many lectures might be devoted to its discussion. But it is foreign to my plan so to discuss it; as to do so would seriously trench upon the time which should be devoted to the consideration of other branches of our enquiry.

I shall next consider the effects of manures, exhaustion, and variations of season, on the amounts of produce, and on the composition of the produce, of different crops, the effects of fallow, and the benefits arising from a rotation of crops.

Subsequently, I propose to take up the subject of the feeding of animals, for the production of meat,

milk, and manure, and for the exercise of force—that is, for their labour. Also, if opportunity should occur, to treat of the question of the application of town-sewage to the land.

Finally, I should observe that, throughout the illustrations which I shall bring before you, it will be my endeavour to keep in view the bearing of the data with which I shall have to deal, on the important question of compensation for unexhausted improvements, so much in discussion at the present time.

The first experiments on crops to which I shall direct attention, will be those on the cereals; for, although bad seasons, and foreign competition, have of late tended to lessen the relative importance of these products to the British farmer, the experimental evidence obtained, both in the field and in the laboratory, is more complete in regard to them than to any other crops; and the discussion of the results, will afford the opportunity of considering important questions of wider interest to agriculture, than those exclusively relating to the production of the cereal crops themselves.



ON
AGRICULTURAL INVESTIGATION;

BEING

A LECTURE DELIVERED OCTOBER 27, 1884,

AT

RUTGERS COLLEGE, NEW BRUNSWICK, N.J.

UNDER THE AUSPICES OF

THE NEW JERSEY AGRICULTURAL EXPERIMENT STATION,
THE STATE BOARD OF AGRICULTURE, AND
THE STATE AGRICULTURAL COLLEGE;

BY

JOSEPH HENRY GILBERT, M.A., LL.D., F.R.S.

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IN THE UNIVERSITY OF OXFORD.



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NOTE ON DR. GILBERT'S LECTURE.

It has been announced that Sir John Bennet Lawes, in arranging for the perpetual maintenance of the great work of Rothamsted, makes provision for a representative of that establishment to visit America every other year and lecture at appropriate places.

Dr. Gilbert was in the United States in 1882, and when it was known that he was to come again in 1884, efforts were made to have him attend the fifth annual meeting of the Society for the Promotion of Agricultural Science. As his various engagements unfortunately prevented his being in Philadelphia at the time desired, arrangements were there made to secure lectures from him at other places. He accordingly visited Lansing, Michigan, and New Brunswick, New Jersey, for the purpose, and found appreciative audiences at both places.

The lecture at Rutgers College was under the joint auspices of the New Jersey Agricultural Experiment Station, State Agricultural College, and State Board of Agriculture.

The Society for the Promotion of Agricultural Science, having intended this lecture to be a part of its proceedings at Philadelphia, have asked and obtained permission to first publish the same in this pamphlet. For this purpose the text has been carefully revised and the tables verified by Dr. Gilbert. This kind attention is gratefully acknowledged by

THE EXECUTIVE COMMITTEE.

NOTE ON THE RE-PRINT IN 1889.

With the exception of a few typographical corrections, the addition of the *Table of Contents* at the top of the next page, and some corresponding cross-titles in the body of the pamphlet, this is strictly a reprint of the Lecture as published in America, as above referred to.

It may be added that, so far as the results relating to the Growth of Wheat are concerned (p. 7 *et seq.*), substantially the same matter formed the basis of a Lecture given at the Royal Agricultural College, Cirencester, on June 16, 1885, so that this may, so far, also stand for the separate publication of that Lecture, which was the first of a series given at Cirencester on the Rothamsted Experiments; the second being on Barley, the third on Root-crops, and the fourth on Potatoes, each of which has already been separately published.

J. H. GILBERT.

LECTURE ON AGRICULTURAL INVESTIGATION.

J. H. GILBERT.

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*Mr. President, Professors and Students of Rutgers College,
and Ladies and Gentlemen:*

I ESTEEM it a high honour and a great responsibility to be called upon to address you on the present occasion ;—an honour because, perhaps, I am not assuming too much in supposing that I owe the invitation to do so to the fact that the joint labours of Sir John Bennet Lawes and myself, in the furtherance of agricultural progress, which have now extended over a period of more than forty-one years, are held in some appreciation in this country ;—and a responsibility, because I know that I have before me representatives of the best agricultural science in the Eastern States.

On hearing from Sir John Lawes, before leaving home, that I might probably be asked to lecture at some Agricultural Institutions in America, I at once decided that it would be inappropriate for me to attempt to discuss, in any detail, American agricultural practices or experiments ; that in these matters I should be a learner rather than a teacher ; and that it would be more suitable for me to give some account of the results obtained at Rothamsted, leaving my audience to decide for themselves, in great measure, how far the facts and the conclusions were applicable to American conditions.

In Germany and France very much good work has been done, both in the laboratory and feeding-shed, during the last thirty years or more ; but in Germany, at any rate, we have it on the authority of Prof. Mærcker of Halle, one of their leading agricultural chemists, that systematic field experiments are almost abandoned in that country. In 1880, Prof. Mærcker stated that belief in their value was greatly diminished, and that by some they were declared to be of no value. It

was objected that the chemists of the Agricultural Stations have neither the means nor the technical knowledge necessary for carrying out such experiments successfully; that neither the amount of land nor the funds at their disposal were such as to admit of any safe deductions for application in practical agriculture from the results; and that purely physiological problems could be better investigated in the laboratory or in the greenhouse. He remarked that, owing to the errors necessarily incident to field experiments conducted by those not acquainted with practical agriculture, the confidence of the practical farmer in the results has been shaken. Indeed, owing to the difficulties and the cost of such inquiries, if conducted in a truly scientific manner, so as to be applicable for the solution of questions of fundamental and general interest, Prof. Mærcker concluded that the only field experiments which it was practicable to carry out in Germany were such as should be conducted by the practical farmer himself, to test the applicability to practice, of results and conclusions otherwise arrived at; and that, to insure that even such experiments should not be misleading, similar ones should be conducted on different descriptions of soil, and for several years in succession.

That the great cost of scientifically conducted field experiments should have prevented the more extended prosecution of them, is perhaps not surprising when I tell you that the Rothamsted field experiments, independently of all the laboratory investigations connected with them, cost considerably more than £1000 annually; whilst those which have been undertaken by the Duke of Bedford at Woburn for the past seven years, on behalf of the Royal Agricultural Society of England, and which are under the direction of Dr. Voelcker, cost not much less than this.

At various institutions in America, and preëminently at the New Jersey Agricultural Experiment Station, very much good work is being done of the character prosecuted with so much success in Germany, and recommended by Prof. Mærcker to be still further followed up; and whilst such work should be continued and extended, surely investigations of a more permanent value, and of more general application, should not be neglected. Nor can it be supposed that in so wealthy a country as America, where there is so much munificence and public spirit displayed in all matters of progress, the cost of scientifically conducted agricultural experiments will be any obstacle.

This brings me to the special subject-matter of my lecture, which is to illustrate the value of *long continued* and *carefully conducted* experiments, by reference to the results of one series of such experiments conducted at Rothamsted,—namely, those on the growth of wheat for more than forty years in succession on the same land—*without manure, with farm-yard manure*, and with a *great variety of chemical manures*.

But, before entering upon the details of this subject, it will be well to give some account of the scope and plan of the whole investigation, of which these special results only form a part.

At Rothamsted, no questions of mere local interest or economy are undertaken. The object is rather to investigate the principles underlying fundamental practices; and whilst results obtained in one locality, on one description of soil, and with one character of climate, require to be carefully studied before conclusions applicable to other localities and to other countries can be drawn, yet it is believed that the results which have been obtained are of very general and wide application.

The general scope and plan of the field experiments has been—to grow some of the most important crops of rotation, each separately, year after year, for many years in succession on the same land, without manure, with farm-yard manure, and with a great variety of chemical manures, the same description of manure being, as a rule, applied year after year on the same plot. Experiments with different manures on the mixed herbage of permanent grass-land, on the effects of fallow, and on an actual course of rotation, without manure, and with different manures, have likewise been made. Field experiments have thus been conducted for the periods, and over the areas, indicated in the following table :

ROTHAMSTED FIELD EXPERIMENTS.

CROPS.	DURATION, YEARS.	AREA, ACRES.	PLOTS.
Wheat (various manures).....	41	13	37
Wheat alternated with fallow.....	33	1	2
Wheat (varieties)	15	4-8	About 20
Barley (various manures)	33	4½	29
Oats (various manures)	10½	½	6
Beans (various manures)	32½	1½	10
Beans (various manures).....	27½	1	5
Beans alternated with wheat	28½	1	10
Clover (various manures)	30½	3	18
Various Leguminous Plants	7	3	17
Turnips (various manures)	28½	8	40
Sugar Beet (various manures)	5	8	41
Mangel Wurzel (various manures)	9	8	41
Total Root Crops	42		
Potatoes (various manures).....	9	2	10
Rotation (various manures).....	37	2½	12
Permanent Grass (various manures).....	29	7	22

(1) Including 1 year fallow.

(2) " 1 " wheat and 5 years fallow.

(3) " 4 years fallow.

(4) " 2 " "

(5) Clover, 12 times sown, 8 yielding crops, but 4 of them very small, 1 year wheat, 5 years barley, 12 years fallow.

(6) Including barley without manure 3 years (11th, 12th and 13th seasons).

Samples of all the experimental crops are brought to the laboratory. Weighed portions of each are partially dried and preserved for future reference or analysis. Duplicate weighed portions of each are dried at 100° C., the dry matter determined, and then burnt to ash. The quantities of ash are determined and recorded, the ashes themselves being preserved for reference or analysis. In a large proportion of the samples the total nitrogen is determined, and in some the amount existing as albuminoids, amides, and nitric acid. In selected cases, illustrating the influence of season, manures, exhaustion, &c., complete ash-analyses have been made, numbering in all more than 700. Also in selected cases, illustrating the influence of season and manuring, quantities of the experimentally grown wheat-grain have been sent to the mill, and the proportion and composition of the different mill-products have been determined. In the sugar-beet, mangel-wurzel, turnips, and potatoes, the sugar in the juice has, in many cases, been determined, by polariscope, or by copper, or both. In the case of the experiments on the mixed

herbage of permanent grass-land, besides the samples taken for the determination of the chemical composition (dry matter, ash, nitrogen, woody fibre, fatty matter, and composition of ash), carefully averaged samples have frequently been taken for the determination of the botanical composition.

Samples of the soils of most of the experimental plots have been taken from time to time, generally to the depth of nine, eighteen, and twenty-seven inches, and sometimes even to four times this depth. In this way more than fifteen hundred samples have been taken, submitted to partial mechanical separation, and portions of the sifted soil have been carefully prepared and preserved for analysis. In a large proportion of the samples the loss on drying at different temperatures, and on ignition, has been determined. In most, the nitrogen determinable by burning with soda-lime has been estimated. In many, the carbon, and in some the nitrogen as nitric acid, and the chlorine, have been determined.

Almost from the commencement of the experiments the rain-fall has been measured ; for more than thirty years in a gauge of one-thousandth of an acre area, as well as in an ordinary small funnel-gauge of five inches diameter. From time to time the nitrogen as ammonia (and sometimes as nitric acid) has been determined in the rain-waters, also chlorine in many samples.

Three drain-gauges, for the determination of the quantity and composition of the water percolating, respectively through twenty inches, forty inches, and sixty inches depth of soil (with its subsoil in natural state of consolidation), have also been constructed. Each of the differently manured plots of the permanent experimental wheat-field having a separate pipe-drain, the drainage waters have been, and are frequently, collected and analysed.

For several years in succession, experiments were made to determine the amount of water given off by plants during their growth. In this way various plants, including representatives of the gramineous, the leguminous, and other families, have been experimented upon ; also ever-green and deciduous trees.

Experiments upon the feeding of animals were commenced in 1847, and have been continued at intervals up to the present time. The following points have been investigated :

1. The amount of food, and of its several constituents, consumed in relation to a given live-weight of animal within a given time.
2. The amount of food, and of its several constituents, consumed to produce a given amount of increase in live-weight.
3. The proportion, and relative development, of the different organs or parts of different animals.
4. The proximate and ultimate composition of the animals, in different conditions as to age and fatness, and the probable composition of their increase in live-weight during the fattening process.
5. The composition of the solid and liquid excreta (the manure) in relation to that of the food consumed.
6. The loss or expenditure of constituents by respiration and the cutaneous exhalations—that is, in the mere sustenance of the living meat-and-manure-making machine.

Several hundred animals—oxen, sheep, and pigs—have been submitted to experiment. The amount, and the relative development, of

TABLE I.

Wheat grown for forty years in succession on the same land, Broadbalk Field, Rothamsted. Results showing the effects of exhaustion, and of manure-residue. Quantities per acre. Produce—Dressed Grain in bushels.

	14 Tons Farm Yard Manure, every year.	Without Manure every year.	Mixed Mineral Manure alone.	Mixed Mineral Manure alone, — blue; Ammonium Salts alone = 86 lbs. Nitro- gen, — yellow; alternately.		Mixed Min. Manr. Am. Salts. 172 lbs. N. 13 years, 1852-'64. Unman'd since.	Mineral Manure alone—blue; Ammonium Salts alone (86 lbs. Nitro- gen)—yellow; Min. & Amm. Salts, —green; Unmanured—white.	
Plot Nos.	2	3	5	17	18	16	10a	10b
Harvests.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.
1844	20½	15					15½	
1845	32	23½					31½	
1846	27½	18					27½	17½
1847	29½	16½					25½	25½
1848	25½	14½					19½	25½
1849	31	19½					32½	32½
1850	28½	15½					27	18
1851	29½	15½					28½	28½
8 yrs. '44-'51	28	17½	29	30½	28½	30½	26	24½
1852	27½	13½	16½	24½	14½	28½	21½	22½
1853	19½	5½	10½	8½	19½	25½	10	15½
1854	41½	21½	24½	44½	23½	49½	34½	39½
1855	34½	17	18½	18	33½	33½	20	28½
1856	36½	14½	19½	31	11½	37½	24½	27½
1857	41½	20	23½	26½	40½	49½	29½	34½
1858	38½	18	18½	33½	21½	41½	22½	27½
1859	36½	18½	20½	20½	32½	34½	19	25½
1860	32½	12½	15½	25½	15½	32½	15½	18½
1861	34½	11½	15½	18½	32½	37	12½	16
1862	38½	16	17½	27½	18½	36½	23½	24½
1863	44	17½	19½	21½	46½	55½	39½	43½
1864	40	16½	16½	36½	17½	51½	32½	36½
1865	37½	13½	14½	17	31½	32½	25½	30½
1866	32½	12½	13½	26½	12½	17½	26½	28½
1867	27½	8½	9½	10½	23½	14½	18½	19½
1868	41½	16½	17½	37½	18½	22½	24½	27½
1869	38½	14½	15½	16½	22½	16½	20½	19½
1870	36½	15	16½	34½	10	18½	21½	23½
1871	39	9½	11½	16	28½	13½	10½	10
1872	31½	10½	12½	25½	13	13½	18	18½
1873	26½	11½	12½	11½	20½	12½	19½	20½
1874	39½	11½	13	33½	14	11½	25½	27½
1875	28½	8½	9½	11½	25½	10½	12½	14½
1876	23½	8½	10½	26½	16½	11	12½	14½
1877	24½	8½	11½	10	12½	9½	17½	18½
1878	28½	12½	14½	29	15½	13½	27½	29½
1879	16	4½	5½	3½	20½	4½	4	4½
1880	38½	11½	17½	32½	15	14½	10½	13½
1881	30½	13½	12½	13½	32	13½	18½	19½
1882	32½	11	12½	31	15½	10½	23½	26½
1883	35½	13½	15½	15½	38½	15½	17½	18½

AVERAGES.

4 yrs. '52-'55	30½	14½	17½	16½	30½	31	21½	26½
4 yrs. '56-'59	38	17½	20½	21½	34½	41	23½	28½
4 yrs. '60-'63	37½	14½	17½	16½	33	31½	22½	25½
4 yrs. '64-'67	34½	12½	13½	14½	29½	(2) 21½	25½	28½
4 yrs. '68-'71	38½	13½	16	17½	30½	17½	19½	20
4 yrs. '72-'75	31½	10½	12	12½	26½	12	18½	20½
4 yrs. '76-'79	23	8½	10½	9½	22½	9½	15½	16½
4 yrs. '80-'83	34½	12½	14½	14½	33½	13½	17½	19½
8 yrs. '52-'59	34½	16½	19	16½	32½	31½	22½	27½
8 yrs. '60-'67	35½	13½	15½	16½	31½	(3) 32½	24	27½
8 yrs. '68-'75	35½	12½	14	15	28½	(4) 16½	19	20½
8 yrs. '76-'83	28½	10½	12½	12½	27½	11½	16½	18½
16 yrs. '52-'67	35½	14½	17½	17½	31½	(5) 13½	23½	27½
16 yrs. '68-'83	31½	11½	13½	13½	28½	(6) 14½	17½	19½
32 yrs. '52-'83	33½	13½	15½	15½	30	24½	20½	23½
40 yrs. '44-'83	32½	14						

(1) Average of 5 years, 1860—1864, inclusive.

(2) Average of 3 years, 1865—1867, inclusive.

(3) Average of 5 years, 1860—1864, inclusive.

(4) Average of 11 years, 1865—1875, inclusive.

(5) Average of 13 years, 1852—1864, inclusive.

(6) Average of 19 years, 1865—1883, inclusive.

the different organs and parts were determined in two calves, two heifers, fourteen bullocks, one lamb, two hundred and forty-nine sheep, and fifty-nine pigs. The percentages of water, mineral matter, fat, and nitrogenous substances, were determined in certain separated parts, and in the entire bodies, of ten animals,—namely, one calf, two oxen, one lamb, four sheep, and two pigs. Complete analyses of the ashes, respectively, of the entire carcasses, of the mixed internal and other “offal” parts, and of the entire bodies, of each of these ten animals, have also been made.

From the data provided as just described as to the chemical composition of the different descriptions of animal, in different conditions as to age and fatness, the composition of the increase whilst fattening, and the relation of the constituents stored up in increase to those consumed in food, have been estimated. To ascertain the composition of the manure in relation to that of the food consumed, oxen, sheep, and pigs have been experimented upon. The loss or expenditure of constituents, by respiration and the cutaneous exhalations, has not been determined directly, but only by difference,—that is, by calculation, founded on the amounts of dry matter, ash, nitrogen, &c., in the food, and in the (increase) fæces, and urine.

Independently of the points here enumerated, the results obtained have supplied data for the consideration of the following questions:

1. The characteristic demands of the animal body, for nitrogenous or non-nitrogenous constituents of food, in the exercise of muscular power.
2. The sources in the food of the fat produced in the animal body.
3. The comparative characters of animal and vegetable food in human dietaries.

RESULTS OF EXPERIMENTS AT ROTHAMSTED, ON THE GROWTH OF WHEAT FOR FORTY YEARS IN SUCCESSION ON THE SAME LAND.

Having given a brief outline of the scope and plan of the investigations that have been in progress at Rothamsted for so many years, I propose to draw my illustrations as to the character and significance of the results obtained, mainly from those relating to the growth of wheat for more than forty years in succession on the same land:

1. Without manure.
2. With farm-yard manure.
3. With a great variety of chemical manures, both individual constituents and mixtures.

Table I. gives the number of bushels of dressed grain per acre without manure, and with farm-yard manure, in each of the forty years, 1844 to 1883 inclusive; and on some of the artificially manured plots, mainly selected to illustrate the effects of exhaustion and of manure-residue. In most cases in this table, and in all cases in the subsequent tables, the results obtained on the artificially manured plots are only given for the last thirty-two of the forty years, as during the first eight years the manures were not the same year after year on the same plot as they were subsequently.

Without Manure.

After a five-course rotation since manuring (turnips, barley, peas, wheat, oats), the first experimental wheat crop was harvested in 1844. The highest yield of the series was $23\frac{1}{4}$ bushels in 1845, and the lowest

was $4\frac{3}{4}$ bushels in 1879. Other yields have been $21\frac{1}{8}$ bushels in 1854, 20 in 1857, only $5\frac{1}{8}$ in 1853, and only 8–9 bushels in 1867, 1875, 1876, and 1877.

In the lower division of the table (I.) the average produce is given for each four years, each eight years, each sixteen years, and for the thirty-two years from 1852 to 1883 inclusive; also for the whole period of forty years. Without manure, the average annual produce over the four-year period was $14\frac{1}{8}$, $17\frac{3}{4}$, $14\frac{1}{8}$, $12\frac{3}{4}$, $13\frac{3}{4}$, $10\frac{1}{8}$, $8\frac{1}{8}$, and $12\frac{1}{8}$ bushels; over the eight-year periods, $16\frac{1}{8}$, $13\frac{1}{8}$, $12\frac{1}{4}$, and $10\frac{1}{8}$; over the sixteen-year periods, $14\frac{1}{8}$ and $11\frac{1}{8}$; over the thirty-two years, $13\frac{1}{8}$, and over the forty years, 14 bushels. With such wide variations due to season, it is very difficult to estimate the rate of decline due to exhaustion. Excluding the very bad seasons, the decline due to gradual exhaustion is reckoned at from one-fourth to one-third of a bushel per acre per annum.

It is estimated that over a period of thirty years, the unmanured plot yielded an average of 18.6 lbs. of nitrogen per acre per annum in the crop, and lost a minimum of 10.3 lbs. in drainage, in all 28.9 lbs.; whilst on the mixed mineral manure plot (5), it is estimated that the crop removed an average of 20.3 lbs. of nitrogen, and that at least 12 lbs. were lost by drainage, or in total 32.3 lbs. Further it is estimated that the soils lost to the depth of twenty-seven inches about two-thirds of these amounts; leaving, say, 10 lbs. more or less to be otherwise accounted for. Of this, the rain, &c., would supply 5 lbs., or perhaps rather more, and the seed about 2 lbs., so that there is but little to be provided from all other sources. Lastly, as at the commencement the soil was, agriculturally speaking, exhausted, the nitrogen supplied by it would be largely due to old accumulations.

Farm-yard Manure every Year.

In the application of farm-yard manure every constituent is supplied in excess. The highest yields of the series of years were 44 bushels in 1863, $41\frac{3}{4}$ in 1868, $41\frac{1}{4}$ in 1857, and $41\frac{1}{8}$ in 1854. The lowest yields were 16 bushels in 1879, $19\frac{1}{8}$ in 1853, $20\frac{1}{8}$ in 1844, $23\frac{1}{8}$ in 1876, and $24\frac{1}{8}$ in 1877.

The average produce per acre per annum over each of the five eight-year periods was 28, $34\frac{3}{8}$, $35\frac{3}{4}$, $35\frac{1}{4}$, and $28\frac{1}{8}$ bushels. Excluding the first eight years, and several of the recent very bad seasons, the average produce is about 35 bushels per acre per annum.

On the farm-yard manure plot, the first nine inches of soil show a great accumulation; it is nearly twice as rich in nitrogen as any other plot, yet this richness is not proof against bad seasons; nor are the highest amounts of produce in the field obtained on this plot.

Thus, without manure, or with mineral manure alone, there is a gradual decline in yield, and with this a marked reduction in the nitrogen of the soil. With farm-yard manure, on the other hand, there is great accumulation, and yet not the fullest crops, a large proportion of the constituents becoming very slowly available.

Various Artificial Manures.

The next question is, which constituents of farm-yard manure are the most effective for wheat in this agriculturally exhausted rather heavy soil, with a raw clay subsoil. The first illustrations on this point will be drawn from Table II. (p. 9).

TABLE II.

*Wheat grown for forty years in succession on the same land,
Broadbalk Field, Rothamsted : commencing 1844.*

Results showing the effects of different manures for 32 years, 1852-83 inclusive. *Quantities per acre. Produce—DRESSED GRAIN IN BUSHEL.*

Plots.	Superphosphate, and Sulphates Potash, Soda, and Magnesia.					Sodium Nitrate alone. =86 lbs. Nitrogen.
	Alone.	& Amm.-salts =43 lbs. Nitrogen.	& Amm. salts =86 lbs. Nitrogen.	& Amm.-salts =129 lbs. Nitrogen.	& Sodium Nitrate=86 lbs. Nitrogen.	
Harvests.	5	6	7	8	9a	9b
1852	167	207	263	271	251	241
1853	101	181	231	231	111	101
1854	241	341	451	481	381	381
1855	111	28	33	311	291	251
1856	191	271	361	391	321	26
1857	231	351	411	481	431	361
1858	181	281	391	411	371	231
1859	201	291	341	341	30	241
1860	151	22	271	311	321	191
1861	151	271	35	351	331	131
1862	171	281	351	391	431	251
1863	191	341	531	551	551	411
1864	161	311	451	491	511	331
1865	141	25	401	431	441	291
1866	131	201	291	321	321	301
1867	91	151	221	301	291	221
1868	171	281	391	461	471	271
1869	151	211	281	341	39	241
1870	181	301	401	451	451	261
1871	111	17	221	271	341	171
1872	121	201	291	351	401	231
1873	121	151	22	271	351	211
1874	13	251	391	401	381	211
1875	91	161	251	30	301	161
1876	101	151	231	291	331	13
1877	111	141	191	241	401	271
1878	141	221	311	381	371	231
1879	51	101	161	201	22	41
1880	171	27	341	351	341	101
1881	121	211	261	301	351	221
1882	121	231	351	37	317	241
1883	151	271	361	411	431	191
AVERAGES.						
4 ys. '52-55	171	251	321	321	261	241
4 ys. '56-59	201	301	381	41	36	271
4 ys. '60-63	171	291	38	401	411	251
4 ys. '64-67	191	231	341	39	391	29
4 ys. '68-71	16	241	321	381	411	237
4 ys. '72-75	12	191	291	311	361	207
4 ys. '76-79	101	151	221	281	331	171
4 ys. '80-83	141	241	331	361	361	191
8 ys. '52-59	19	271	351	361	311	261
8 ys. '60-67	151	261	361	391	401	271
8 ys. '68-75	14	22	31	36	39	221
8 ys. '76-83	121	201	28	321	341	181
16 ys. '52-67	171	27	351	381	351	261
16 ys. '68-83	191	211	291	341	361	201
32 ys. '52-83	151	241	321	361	361	231
Excess of average crop over Plot 5 in bush.	—	81	171	21	21	81

Taking the average for each eight or sixteen years of the thirty-two, it is seen that in every case, even with full mineral as well as nitrogenous manure, there is more or less decline in the later periods, including so many bad seasons; excepting on 9a, where the nitrate of soda is always applied in the spring. The low results or great decline, on 9b, where the nitrate is used alone, show the want of minerals.

The average of the thirty-two years of mineral manure alone shows an increase of only $2\frac{1}{2}$ bushels over that of the unmanured plot, though during the preceding eight years it had been manured, whilst the unmanured plot had already grown eight unmanured wheat crops. The addition to the mineral manure of the first 43 lbs. of nitrogen (plot 6) gives an average annual increase of $8\frac{1}{2}$ bushels, the second 43 lbs. (plot 7) an increase of $8\frac{1}{2}$, and the third 43 lbs. (plot 8) only $3\frac{1}{2}$ bushels increase. This result affords an illustration of the inapplicability of conclusions from manure experiments, when the condition of the land is too high already, or when an excess of manure is applied. A given quantity of nitrogen in the form of nitrate, yielded more produce than an equal quantity in the form of ammonia. The nitrate, being always applied in the spring, was not subject to winter drainage. It is, however, very soluble, and becomes rapidly distributed and available; but it is, at the same time, very subject to drainage after sowing, if heavy rains follow. Prior to 1878, the ammonium-salts were applied in the autumn, and a great loss of nitrogen by winter drainage, chiefly as nitrates, was proved. To the loss of nitrogen by drainage reference will be made further on.

Thus, minerals not being deficient, the increase was in proportion to the available nitrogen, when it was not applied in excess.

It will be of interest here to call attention to the actual amounts of carbon assimilated per acre per annum in wheat, and in barley, under different conditions of manuring; also to the increased amount assimilated under the influence of nitrogenous manures.

In Table III. are shown the estimated amounts of carbon, yielded per acre per annum, in wheat over twenty years, and in barley over twenty years; each with the complex mineral manure alone, and each with the same mineral manure and given quantities of nitrogen in addition, supplied as ammonium-salts, or as nitrate. The gain of carbon by the use of the nitrogenous manure is also given.

TABLE III.

Yield and gain of Carbon per acre per annum in crops at Rothamsted.

	Average Carbon per acre, per annum.	
	Actual	Gain.
Wheat 20 years, 1852-1871.		
Complex Mineral Manure	lbs. 988	lbs. —
Complex Min. Man. and 43 lbs. Nitrogen, as Ammonia.....	1590	602
Complex Min. Man. and 86 lbs. Nitrogen, as Ammonia.....	2222	1234
Complex Min. Man. and 86 lbs. Nitrogen, as Nitrate.....	2500	1512
Barley 20 years, 1852-1871.		
Complex Mineral Manure.....	1138	—
Complex Min. Man. and 43 lbs. Nitrogen, as Ammonia ...	2088	950

It is quite evident that in the case of these gramineous crops, wheat and barley, which contain a comparatively low percentage of nitrogen, and assimilate a comparatively small amount of it over a given area, there was a greatly increased amount of carbon assimilated by the addition of nitrogenous manure alone. In the case of the wheat, there was much more effect from a given amount of nitrogen supplied as nitrate, which was always applied in the spring, than from an equal quantity as ammonium-salts, which were applied in the autumn, and the nitrogen of which was subject to winter drainage. There is also more effect from ammonium-salts applied to barley than to wheat; the application having been made for the former in the spring, and for the latter in the autumn. It should be observed that there was this greatly increased assimilation of carbon in the wheat and in the barley for more than twenty years, without the addition of any carbon to the soil. It is, indeed, certain that, in the existing condition of our old arable soils, the increased growth of our staple starch-yielding grains is greatly dependent on a supply of nitrogen within the soil. It is equally certain that the increased production of sugar in the gramineous sugarcane, in the tropics, is likewise greatly dependent on the supply of nitrogen within the soil.

It will further be of interest to call attention to the connection between nitrogen accumulation, chlorophyll formation, and carbon assimilation.

TABLE IV.

Relation of Carbon assimilation to Nitrogen accumulation, and to Chlorophyll formed.

	Nitrogen, percentage in Dry Matter.*	Relative Amounts of Chlorophyll.	Carbon per acre per annum=lbs.	
			Actual	Difference.
HAY.				
Gramineæ	1.190	0.77	—	—
Leguminosæ	2.478	2.40	—	—
WHEAT.				
Plot 10a	(1.227)	2.00	1398	-824
Plot 7	(0.566)	1.00	2222	—
BARLEY.				
Plot 1a	(1.474)	3.20	1403	-685
Plot 4a	(0.792)	1.46	2088	—

* The figures given in parentheses are on the substance partially dried, but not fully dried at 100° C.

It should be observed that the amounts of chlorophyll recorded are as stated, *relative*, and not actual; and the figures show the relative amounts for the individual members of each pair of experiments, and not the comparative amounts as between one set of experiments and another. It should further be stated that the chlorophyll determinations were kindly made by Dr. W. J. Russell, F.R.S., of London, in specimens collected at Rothamsted, whilst the wheat and barley were still green, and actively growing.

It will be seen, in the first place, that the separated leguminous herbage of hay contained a much higher percentage of nitrogen in its dry matter than the separated gramineous herbage; and that, with the much higher percentage of nitrogen in the leguminous herbage, there was also a much higher proportion of chlorophyll.

Next, it is to be observed that the wheat plant on plot 10a, manured with ammonium-salts alone, shows a much higher percentage of nitrogen than that of plot 7, with the same amount of ammonium-salts, but with mineral manure in addition. The high proportion of chlorophyll again goes with the high nitrogen percentage; but the last column of the table shows that on plot 10a, with ammonium-salts without mineral manure, with the high percentage of nitrogen and high proportion of chlorophyll in the green produce, there was eventually a very much less assimilation of carbon. The result is exactly similar in the case of the barley; plot 1a being manured with ammonium-salts alone, and plot 4a with the same ammonium-salts and mineral manure in addition.

It is evident that the chlorophyll formation has a close connection with the amount of nitrogen assimilated; but that the carbon assimilation is not in proportion to the chlorophyll formed, if there is not a sufficiency of the necessary mineral constituents available. No doubt there had been as much or more of both nitrogen assimilated, and chlorophyll formed, over a given area, where the mineral as well as the nitrogenous manure had been applied; the lower *proportion* of both in the dry matter being due to the greater assimilation of carbon, and consequent greater formation of non-nitrogenous substance.

The next point to consider is, what is the effect of the unrecovered amount of nitrogen on succeeding crops? This is illustrated by the results in the coloured columns of Table I (facing p. 7). In the table, mineral manure is indicated by blue, nitrogen as ammonium-salts by yellow, and a mixture of the two by green. Plot 5 has been manured continuously for thirty-two years with mineral manure alone; whilst plots 17 and 18 each received mineral manure, and a quantity of ammonium-salts containing 86 lbs. of nitrogen, alternately. Thus we are able, for every year, to compare a plot manured with minerals, succeeding a previous application of ammonium-salts, with a plot receiving mineral manure alone every year. It is seen that, in every case, the application of nitrogen has given a greatly increased yield, frequently doubling that of the plot with mineral manure alone. Again, in every case, the yield of the succeeding year, when the mineral manure was applied, was reduced approximately to that of the plot continuously treated with minerals alone. A glance down the alternately blue and yellow columns of plots 17 and 18, and a comparison with the blue column of plot 5, will bring these results strikingly to view. A comparison of the averages of the periods of four, eight, sixteen, and thirty-two years, of this treatment, clearly shows the essential identity of the results of the continuous and the alternate treatment with mineral manures. The averages for the thirty-two years show an increase in the yield of the mineral-manure years after ammonia, over the yield of plot 5, of only $\frac{3}{8}$ of a bushel per acre per annum in a crop of between fifteen and sixteen bushels. The non-effect, or the absence, of residual nitrogen applied in the form of ammonium-salts, is evident. In other words, nitrogen as ammonium-salts applied in any one year is practically exhausted that year, in the crop or otherwise, leaving practically none for subsequent action.

Again, plot 16, for thirteen years, from 1852 to 1864 inclusive, received annually mixed mineral manure and ammonium-salts, containing a double quantity (172 lbs.) of nitrogen; and since that time, for nineteen years (1864-1883), it has been left unmanured. During the thirteen years of heavy manuring there was a large yield, in two cases exceeding

fifty bushels, with an average for the thirteen years of $39\frac{1}{2}$ bushels. The first three years during which no manure was applied, the average yield was only $21\frac{1}{2}$ bushels, a decrease of nearly one-half, followed in the succeeding periods of four years each by average yields of $17\frac{1}{2}$, 12, $9\frac{1}{2}$, and $13\frac{3}{4}$ bushels; against, for the corresponding periods on plot 3, continuously without manure, $13\frac{3}{4}$, $10\frac{1}{2}$, $8\frac{1}{2}$, and $12\frac{1}{2}$ bushels. Or, taking the average of the nineteen years of yield without manure on plot 16, we have $14\frac{1}{2}$ bushels, against, over the same years, $13\frac{1}{2}$ bushels, on plot 5, with mineral manures only, since 1852, and $11\frac{1}{2}$ bushels on plot 3, unmanured since 1839. It is fair to presume, moreover, that some of the greater yield of plot 16, from 1864-1883, over that of plot 3, is due to the residue of the mixed mineral manure, which, as will be seen further on, has some effect on succeeding crops.

If, as the above results have demonstrated, there is practically no residue from previous application of ammonium-salts, the question arises, What becomes of the nitrogen of the manure not taken up by the crop? This point is illustrated by the results given in Table V. The plots there tabulated all received the same amount of nitrogen in manure, with differing mineral manures, and they are given in the order of their average annual increased yield of nitrogen in the crops over plot 5, with mineral manure alone. The first column shows the estimate of average annual increased yield of nitrogen per acre in the crops; the second, the estimated annual loss of nitrogen as nitric acid by drainage; the third, the estimated annual excess of nitrogen in the surface-soil over that on plot 5 with the mineral manure alone; and the last column shows the relation which that excess in the soil bears to 100 increased yield of nitrogen in the crops.

The plots were manured as follows

- Plot 10—Amm.-salts = 86 lbs. N.
- „ 11—Amm.-salts = 86 lbs. N., and superphosphate.
- „ 12—Amm.-salts = 86 lbs. N., superphosphate and soda.
- „ 13—Amm.-salts = 86 lbs. N., superphosphate and potash.
- „ 14—Amm.-salts = 86 lbs. N., superphosphate and magnesia.
- „ 7—Amm.-salts = 86 lbs. N., and mixed mineral manure.
- „ 9—Nitrate of soda = 86 lbs. N., and mixed mineral manure.

TABLE V.

BROADBALK EXPERIMENTAL WHEAT-FIELD.

Estimated Nitrogen per acre per annum.

PLOTS.	In Crops over Plot 5.	Lost by Drainage over Plot 5.	In surface soil, 9 inches deep, over Plot 5.	Excess in surface soil to 100 increase in Crop.
	lbs.	lbs.	lbs.	lbs.
10	12.4	31.2	4.8	38.7
11	17.7	28.5	11.6	65.5
12	22.2	24.5	14.6	65.8
13	23.4	25.6	17.8	76.1
14	24.1	27.5	15.5	64.3
7	25.9	19.0	19.3	74.5
9	26.5	23.7	18.5	71.2

It is seen that the increased yield of nitrogen in the crops varied exceedingly with the same amount supplied in manure, according to the condition as to supply of mineral constituents. Plot 10, with the ammonium-salts alone, gives the smallest increased yield of nitrogen in the crop; and plots 7 and 9, with the most complete mineral manure, each more than twice as much; the other plots giving intermediate amounts.

The order of the estimated loss of nitrogen by drainage is almost the converse of that of the increased yield in the crops. Plot 10, which gives the least increased yield in the crop, shows the greatest loss by drainage; and plots 7 and 9, which yield the greatest increase in the crop, show the least loss by drainage.

The excess in the soils (over plot 5) is obviously much more in the order of the increased yield in the crops. Plot 10, with the least in the increase of crop, and the most in the drainage, shows the least excess in the soil; whilst plots 7 and 9, with the greatest increased yield in the crop, and the least loss by drainage, show the greatest excess in the soil.

It is clear, therefore, that whilst the excess in the soil has no direct relation to the amount supplied in the manure, it has a very obvious relation to the increased yield in the crop; in other words, to the amount of growth. The last column of the table brings this out more clearly. Excepting in the case of plot 10, with the ammonium-salts alone, there is a general uniformity in the proportion of the excess in the soil over plot 5 to the increased yield in the crop over plot 5; and the variations, such as they are, have an obvious connection with the conditions of growth. Thus plots 11, 12, and 14, all with a deficient supply of potash, show approximately equal proportions retained in the soil for 100 of increase in the crop. Plots 13, 7, and 9, again, all with liberal supplies of potash, show higher, but approximately equal, proportions retained in the surface-soil for 100 of increased yield in the crop.

Upon the whole, it is obvious that the relative excess of nitrogen in the soils of the different plots is little, if at all, due to the direct retention by the soil of the nitrogen of the manure, but it is almost exclusively dependent on the difference in amount of the residue of the crops—of the stubble and roots, and perhaps of weeds.

This leads to the consideration of the actual differences in the crop with equal nitrogen supply and different mineral supply. This is illustrated by the results in Table VI., which shows the effects of mineral manures alone, of ammonium-salts alone, and of ammonium-salts with different mineral manures.

TABLE VI.

*Wheat grown for forty years in succession on the same land.
Broadbalk Field, Rothamsted.*

Results showing the effects of Mineral Manures alone, and when used in addition to Ammonium-Salts.

Quantities per acre. Produce: Dressed Grain in bushels.

400 lbs. Ammonium-Salts = 86 lbs. Nitrogen per acre per annum.								
	Mixed Mineral Manure alone.	Alone, 1852 and since. Previously Min. Man. 1844. Am.-Salts 1845-61.	Alone, 1852 and since. Previously Min. Man. 1844, '48 and '50. Am.-Salts 1845, '7, '8, '9 and '61.	And Super-phosphate.	And Super-phosphate and Sulphate of Soda.	And Super-phosphate and Sulphate of Potash.	And Super-phosphate and Sulphate of Magnesia.	And Super-phosphate and Sulphates of Potash, Soda, and Magnesia.
Plot Nos.—	Plot 5	Plot 10a	Plot 10b	Plot 11	Plot 12	Plot 13	Plot 14	Plot 7
Harvests. 8 yrs. '44, '51	Bushels. 29	Bushels. 26	Bushels. 24½	Bushels. 28½	Bushels. 28½	Bushels. 27½	Bushels. 27½	Bushels. 29½
1852	16½	21½	22½	23½	24½	24	24½	26½
1853	10½	10	15½	18½	22½	23	22½	23½
1854	24½	34½	39½	43½	45½	44½	44½	45½
1855	18½	20	28½	21½	31½	80½	31½	33
1856	19½	24½	27½	31½	33½	31½	34½	36½
1857	23½	29½	34½	39½	43½	43½	43½	44½
1858	18½	22½	27½	32	37½	37½	38½	39½
1859	20½	19	26½	27½	34½	34½	34½	34½
1860	15½	15½	18½	22½	27½	26½	27½	27½
1861	15½	12½	16	24½	32½	34½	33½	35
1862	17½	23½	24½	26½	33½	32½	31½	35½
1863	19½	39½	43½	45½	54	53½	54	53½
1864	16½	32½	36½	36½	44½	43½	41½	45½
1865	14½	25½	30½	27½	34½	37½	36½	40½
1866	13½	26½	28½	28	28½	24½	28	29½
1867	9½	18½	19½	22½	24½	23½	22½	22½
1868	17½	24½	27½	33½	39½	39½	41½	39½
1869	15½	20½	19½	22½	27½	27½	27½	28½
1870	18½	21½	23½	25½	35½	37	35½	40½
1871	11½	10½	10	11	21½	30½	24½	22½
1872	12½	18	18½	27½	29½	29½	30½	29½
1873	12½	19½	20½	19½	22½	23½	24½	22
1874	13	25½	27½	32½	39½	37½	36½	39½
1875	9½	12½	14½	18	25½	27½	28½	25½
1876	10½	12½	14½	14½	19½	25½	22½	23½
1877	11½	17½	18½	17½	17½	18½	18½	19½
1878	14½	27½	29½	29½	29½	29½	32½	31½
1879	5½	4	4½	11½	14	16	16½	16½
1880	17½	10½	13½	25½	29½	33	31	34½
1881	12½	18½	19½	21½	23½	28½	27½	26½
1882	12½	23½	26½	30½	34½	32½	34½	35½
1883	15½	17½	18½	26½	30½	34½	33½	36½
AVERAGES.								
4 yrs. '52, '55	17½	21½	26½	26½	31½	30½	30½	32½
4 yrs. '56, '59	20½	23½	28½	32½	37½	36½	37½	38½
4 yrs. '60, '63	17½	22½	26½	29½	37	36½	36½	38
4 yrs. '64, '67	13½	25½	25½	28½	33	32½	32½	34½
4 yrs. '68, '71	16	19½	20	23	30½	33½	32½	33½
4 yrs. '72, '75	12	18½	20½	24½	29½	29½	29½	29½
4 yrs. '76, '79	10½	15½	16½	18½	20	22½	22½	22½
4 yrs. '80, '83	14½	17½	19½	26	29½	31½	31½	33½
8 yrs. '52, '59	19	23½	27½	29½	34½	33½	34½	35½
8 yrs. '60, '67	16½	24	27½	29½	35	34½	34½	36½
8 yrs. '68, '75	14	19	20½	23½	30	31½	30½	31
8 yrs. '76, '83	12½	16½	18½	22½	24½	27	27	28
16 yrs. '52, '67	17½	23½	27½	29½	34½	34	34½	35½
16 yrs. '68, '83	13½	17½	19½	22½	27½	29½	28½	29½
32 yrs. '52, '83	15½	20½	23½	26½	31	31½	31½	32½
Plot Nos.—	5	10a	10b	11	12	13	14	7

For the thirty-two years,—1852 to 1883 inclusive,—each of the eight differently manured plots received the same manure each year. I will only call special attention to the average yields over periods of sixteen and thirty-two years.

Plot 5, treated with mineral manure only, gave, during the first sixteen years, an average yearly yield of $17\frac{3}{8}$ bushels per acre, during the second sixteen years $13\frac{3}{8}$ bushels, and during the whole period of thirty-two years $15\frac{1}{4}$ bushels.

Plot 10a, treated with ammonium-salts only, gave, during the first sixteen years, an average yearly yield of $23\frac{3}{8}$ bushels per acre, during the second sixteen years $17\frac{3}{4}$ bushels, and during the thirty-two years an average of $20\frac{1}{2}$ bushels. Thus, ammonium-salts alone produced much more than mineral manure alone.

On plot 10b, previous to 1852,—in the years 1844, 1848, and 1850,—mineral manures had been applied, in the other years previous to 1852 (excepting in 1846, when it was unmanured), and subsequently, ammonium-salts only. The effect of the residue of the previously applied mineral manures is apparent on comparison with the yields on 10a.

On plot 10b we find, during the first period of sixteen years, an average yearly yield of $27\frac{3}{8}$ bushels per acre, against $23\frac{3}{8}$ bushels on 10a; during the second period of sixteen years $19\frac{1}{8}$ bushels, against $17\frac{3}{4}$ on 10a; and during the thirty-two years, an average yearly yield of $23\frac{1}{4}$ bushels, against only $20\frac{1}{2}$ on 10a.

Plot 11, with superphosphate but no potash, in addition to the ammonium-salts, gave, during the first sixteen years, an average yearly yield of $29\frac{3}{8}$ bushels per acre, during the second sixteen years $22\frac{3}{8}$ bushels, and during the thirty-two years $26\frac{1}{8}$ bushels.

On plot 12, in addition to the ammonium-salts, superphosphate and sulphate of soda were applied; but potash had been applied prior to 1852. The first sixteen years produced an average yearly yield of $34\frac{3}{8}$ bushels per acre, the second sixteen years of $27\frac{1}{2}$ bushels, and the whole thirty-two years of 31 bushels.

On plot 13, the ammonium-salts, superphosphate, and sulphate of potash were applied, and the average annual produce was, over the first sixteen years 34 bushels, over the second sixteen years $29\frac{1}{4}$, and over the thirty-two years $31\frac{1}{8}$ bushels.

On plot 14, besides the ammonium-salts and superphosphate, sulphate of magnesia was applied, and some potash had been applied prior to 1852. The average annual produce was, over the first sixteen years $34\frac{3}{8}$ bushels, over the second sixteen years $28\frac{3}{8}$ bushels, and over the thirty-two years $31\frac{1}{8}$ bushels.

On plot 7, in addition to the ammonium-salts, superphosphate and the sulphates of potash, soda, and magnesia, were applied, and there was an average yearly yield, during the first sixteen years of $35\frac{3}{8}$ bushels per acre, during the second sixteen years of $29\frac{3}{8}$ bushels, and during the whole thirty-two years of $32\frac{1}{4}$ bushels.

Thus, not only the effect upon the yield of wheat of a direct supply, but of a residue from long previous applications of potash, is very noticeable. This is rendered more obvious by reference to the following table (VII.), in which the pounds per acre of potash and phosphoric acid removed during two periods of ten years each, in the total produce,

and in the grain alone, of the plots last referred to, and some others are given.

TABLE VII.

Potash and Phosphoric Acid in Grain, and in Total Produce.

Ten years, 1852-'61, and ten years, 1862-'71.

PER ACRE IN POUNDS.

PLOTS.	POTASH.				PHOSPHORIC ACID.			
	1852-'61.		1862-'71.		1852-'61.		1862-'71.	
	In Total Produce.	In Grain.	In Total Produce.	In Grain.	In Total Produce.	In Grain.	In Total Produce.	In Grain.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
2	52.6	11.8	53.5	12.4	26.5	19.6	27.3	20.1
3	19.0	5.5	15.3	4.9	10.8	8.2	9.7	7.5
5	26.6	6.6	21.1	5.7	14.7	10.5	12.3	8.8
10a	27.2	7.1	23.1	7.7	13.0	9.6	13.4	10.4
10b	33.3	8.5	25.0	8.7	16.0	12.2	14.8	12.0
11	30.9	9.3	26.0	8.8	19.8	14.9	18.0	13.6
12	45.4	11.4	37.8	11.4	23.2	17.7	21.8	17.0
13	53.2	11.3	55.2	12.2	22.9	17.7	23.3	18.2
14	49.8	11.3	39.1	11.6	22.9	17.9	22.4	17.6
7	56.0	11.9	53.0	12.3	23.8	18.4	23.4	18.5

I will illustrate this point by referring only to the potash. Plots 3, 10a, 10b, and 11, show a deficiency of potash in both grain and total produce compared with the amounts in the produce of plots 2, 12, 13, 14 and 7, on all of which there was a sufficiency, or more or less excess, of potash available. On comparison of these results with the manuring of the plots, we find that in every case the increase of potash in the total crop depends either on a direct annual potash supply, or on a residue from previous applications. The first ten years show more potash in the total produce with the direct supply (13 and 7) than with the residue (12 and 14); but the amount in the grain is essentially the same in each case. In the second ten years there is a greater difference in the amounts of potash in the total produce between the plots having the direct and those having only the residual supply; whilst there is scarcely any difference in the amounts in the grain, but such as it is, it is in accordance with the conditions of supply. Hence it is evident that whilst the plant in its vegetative stages assimilates according to the available supply,—it may be in excess of actual need,—if there is no deficiency, the composition of the final product—the seed—is essentially the same.

We have thus traced the effects of exhaustion, of full manuring, and of nitrogenous and non-nitrogenous manures, on one particular soil. It has been seen how very different is the effect of one and the same manuring in different seasons, but the real extent of this variation is more clearly brought out in Table VIII., which shows the best, the worst, and the average produce, over a period of thirty-two years, under very opposite conditions as to manuring.

TABLE VIII.

Wheat year after year on the same land. Broadbalk Field, Rothamsted.

Produce of the best season, 1863; the worst season, 1879; and average of 32 years, 1852-1883.

Plot No.	Description of Manures—Quantities per acre.	Dressed Grain per acre—Bushels.			
		Best Season, 1863.	Worst Season, 1879.	Difference.	Average 32 yrs. 1852-'83.
3	Unmanured.....	17½	4½	12½	13½
2	Farm-Yard Manure	44	16	28	33½
5	Mixed Mineral Manure, alone	19½	5½	14	15½
6	Mixed Min. Man. and 200 lbs. Amm.-Salts = 43 lbs. Nit.	39½	10½	29½	24½
7	Mixed Min. Man. and 400 lbs. Amm.-Salts = 86 lbs. Nit.	53½	16½	37½	32½
8	Mixed Min. Man. and 550 lbs. Nitrate Soda = 86 lbs. Nit.	56½	22	33½	36½
9	Mixed Min. Man. and 600 lbs. Amm.-Salts = 129 lbs. Nit.	56½	20½	35½	36½

We will confine our attention to the amount of dressed grain per acre in bushels. The difference in yield of the various plots in the best and worst of the thirty-two seasons is very marked. The unmanured, the mineral manured, and the heavily nitrogenous manured plots, all suffered severely. In most cases the difference approaches, and in two cases (Plots 6 and 7, mixed mineral manure, together with 200 and 400 pounds of ammonium-salts, respectively furnishing 43 and 86 pounds of nitrogen) it actually exceeds the average produce of the plots. From these facts we see how easy it is to form wrong conclusions as to the effects of different manures, if experiments are conducted in only one season, or in only a few seasons, and if the characters of the seasons are not studied.

Not only season, but soil and locality must exercise an influence. The Rothamsted results are obtained on one description of soil, and in one locality only. Reference to the following table (IX.) shows the results obtained in experiments conducted at Rothamsted during the same eight years, but in two fields; at the same place in one field for thirty-two years; at Woburn, for seven years; at Holkham, Norfolk, for three years; and at Rodmersham, Kent, for four years. Thus, the experiments were made on very various soils, under various conditions from previous treatment, and in various seasons, yet the general characters of the results are accordant.

TABLE IX.

Results of Experiments on the growth of Wheat by different Manures, on different Soils, in different Localities, and in different Seasons.

MANURES. QUANTITIES PER ACRE.	DRESSED GRAIN PER ACRE—BUSHELS. AVERAGE ANNUAL RESULTS.					
	Rothamsted.			Woburn, Beds, 7 years. 1877-'83.	Holkham, Norfolk, 3 years. 1852-'54.	Rodmers- ham, Kent. 4 years. 1856-'59.
	8 years— 1856-'63.		32 years— 1852-'83.			
	Broadbalk Field.	Hoos Field.	Broadbalk Field.			
Unmanured.....	16	15	13½	15½	18	25½
Mixed Mineral Manure, alone ...	19	16½	15½	16½	19½	28½
Amm.-Salts, alone=86 lbs. N. ...	23½	26½	20½	23½ (1)	27½	31½
Mixed Mineral Manure, and Ammonium-Salts = 86 lbs. N. }	38½	37½	32½	37½	32½	33½

(1) By Ammonium-Salts = only 43 lbs. N.

Not only is there general accordance in the character of the results in different localities, when the averages of a number of years are taken, but the non-effect of the residue from previous application of ammonium-salts is as marked in the sandy soil at Woburn as in the very different soil at Rothamsted. Reference to Table X. will illustrate this. Stack-yard field, Woburn, received mineral manure, and ammonium-salts = 86 lbs. nitrogen, for five successive years. The field was then divided, one portion receiving the same manure as before, and the other the mixed mineral manure, but no nitrogen. In the next year, 1883, the portion which had received nitrogen in the previous year received mineral manures only, and conversely the other portion, which had received mineral manure only in 1882, received both mineral manure and ammonium-salts. It is seen that in each year, 1882 and 1883, the portion which received the nitrogenous manure yielded large crops ($43\frac{1}{2}$ and $45\frac{3}{4}$ bushels); whereas, the portion on which mineral manures alone succeeded ammonium-salts and large crops, yielded very small crops— $13\frac{1}{4}$ and $17\frac{1}{4}$ bushels, respectively, against $14\frac{1}{8}$ and $17\frac{1}{4}$ bushels on the plot where the same mineral manures were used year after year. It is thus seen that there was no available and effective residue where the ammonium-salts had previously been applied. It may be stated, however, that in 1884 there was notable effect from unexhausted residue of nitrogenous manure; the explanation probably being that there had been very little rain, and consequently very little loss by drainage during the winter of 1883-4.

TABLE X.

*Wheat grown year after year on the same land.
Stackyard Field, Woburn.*

Harvests.	Dressed Grain. Bushels.	
1877	43 $\frac{1}{2}$	
1878	27	
1879	31 $\frac{1}{2}$	
1880	28 $\frac{1}{2}$	
1881	43 $\frac{1}{2}$	
1882	(1) 13 $\frac{1}{4}$	(2) 43 $\frac{1}{2}$
1883	(2) 45 $\frac{3}{4}$	(1) 17 $\frac{1}{4}$

(1) Mixed Mineral Manure alone.

(2) Mix. Min. Man. and Ammonia-Salts = 86 lbs. N.

Produce, Imports, and Consumption of Wheat, in the United Kingdom.

Having illustrated the soil conditions necessary for the growth of wheat, it will be well to call attention to one practical application of these long-continued field experiments. For thirty-two years (1852-83) an estimate has been made of the average produce of wheat per acre in the United Kingdom, based upon the yield at Rothamsted on the unmanured, the farm-yard manured, and three of the artificially manured plots taken as one. From this the total yield of the country has been calculated; to this the imports have been added, and the quantity required for seed deducted, the final figure showing the total amount available for consumption, and from this the consumption per head of the population has been reckoned. It may be said at once that these results proved to be very near the truth. But the point of interest to a wheat-growing and wheat-exporting country like America is, the evidence which the results afford as to the constantly increasing requirements of a largely importing country like Great Britain.

The following table (XI.) shows that during the thirty-two years, 1852-3 to 1883-4, inclusive, the area under wheat in the United Kingdom has been reduced by about one-third. The average yield per acre is estimated at 28 bushels; but owing to recent bad seasons, the average for the whole period of thirty-two years was only 27 bushels, that for the first sixteen years having been 28½, but that for the second sixteen years only 25½. Thus there has not only been a reduction in area under cultivation, but in yield per acre, also; this, however, is probably temporary, whilst the reduction in area will doubtless continue.

TABLE XI.

Particulars of Home Produce, Imports, and Consumption of Wheat, in the United Kingdom—32 years, 1852-3 to 1883-4.

Harvest years, Sept. 1 to Aug. 31.	Estimated Home Produce.			Available for consumption.			Available for Consumption per head.		
	Area under Crop.	Average yield per Acre.	Total Home Produce.	Home Produce less 2½ bush. per acre for Seed.	Imports less Exports.	Total.	From Home Produce.	From Imports.	Total.
	Acres.	Bush.	Quarters.	Quarters.	Quarters.	Quarters.	Bush.	Bush.	Bush.
1852-3	4,058,731	22½	11,574,982	10,433,464	5,902,000	16,335,464	3,03	1.71	4.74
1853-4	4,013,963	20½	10,466,473	9,337,546	6,092,000	15,429,546	2.70	1.76	4.46
1854-5	4,036,969	34½	17,563,140	16,427,742	2,983,000	19,410,742	4.73	0.85	5.58
1855-6	4,076,447	27	13,922,801	12,776,300	3,265,000	16,041,300	3.66	0.93	4.59
1856-7	4,213,651	27	14,192,643	13,007,453	4,112,684	17,120,037	3.70	1.16	4.86
1857-8	4,185,974	33½	17,321,221	16,143,915	5,795,687	21,939,602	4.56	1.63	6.19
1858-9	4,131,822	31½	16,309,949	15,147,874	4,555,670	19,703,544	4.24	1.28	5.52
1859-60	4,019,725	26½	13,135,124	12,004,675	4,516,332	16,520,907	3.34	1.26	4.60
1860-1	3,992,667	22½	11,078,948	9,956,012	10,023,968	19,979,980	2.75	2.77	5.52
1861-2	3,898,177	25½	12,271,646	11,175,183	9,099,455	20,274,638	3.06	2.49	5.55
1862-3	3,823,947	29½	13,957,554	12,892,069	9,205,086	22,097,155	3.51	2.51	6.02
1863-4	3,698,629	38½	17,922,048	16,881,807	6,991,270	23,873,077	4.57	1.89	6.46
1864-5	3,685,493	35½	16,216,328	15,179,783	5,500,705	20,680,488	4.08	1.48	5.56
1865-6	3,646,691	30½	13,975,936	12,950,305	7,313,026	20,263,331	3.47	1.95	5.42
1866-7	3,649,584	25½	11,486,091	10,458,645	7,633,033	18,091,678	2.78	2.02	4.80
1867-8	3,628,910	21	9,566,622	8,545,890	9,015,643	17,561,433	2.25	2.38	4.63
1868-9	3,937,275	34	16,733,419	15,626,060	7,719,304	23,345,364	4.09	2.02	6.11
1869-70	3,976,147	27	13,419,496	12,301,208	9,921,526	22,222,731	3.20	2.58	5.78
1870-1	3,761,467	30	14,105,464	13,047,554	8,008,839	21,056,393	3.33	2.05	5.38
1871-2	3,818,848	24	11,456,644	10,382,493	9,316,600	19,699,093	2.62	2.35	4.97
1872-3	3,827,146	24	11,481,438	10,405,053	12,291,463	22,696,516	2.60	3.07	5.67
1873-4	3,658,815	22½	10,290,417	9,261,375	11,301,316	20,562,691	2.29	2.80	5.09
1874-5	3,821,655	22½	13,972,926	12,898,085	11,705,255	24,603,340	3.16	2.87	6.03
1875-6	3,503,709	22½	10,018,414	9,033,000	13,860,079	22,893,079	2.19	3.36	5.55
1876-7	3,114,555	25	9,732,984	8,867,015	12,107,294	20,964,309	2.13	2.91	5.04
1877-8	3,311,859	26½	10,970,633	10,039,073	14,408,628	24,447,701	2.38	3.42	5.80
1878-9	3,372,590	30	12,647,213	11,698,672	14,145,649	25,844,321	2.75	3.32	6.07
1879-80	3,047,752	15½	5,905,020	5,047,840	16,409,933	21,457,773	1.17	3.82	4.99
1880-1	3,057,784	24	9,364,464	8,504,462	16,182,210	24,686,672	1.95	3.72	5.67
1881-2	2,980,066	24	8,880,198	8,047,679	17,200,108	25,247,787	1.83	3.91	5.74
1882-3	3,157,924	25½	10,115,225	9,227,059	19,982,162	29,209,221	2.08	4.50	6.58
1883-4	2,707,949	28	9,477,822	8,616,211	15,815,878	24,432,089	1.92	3.53	5.45
AVERAGES.									
4 yrs. '52-'56	4,046,528	26½	13,381,849	12,243,763	4,560,500	16,804,263	3.53	1.31	4.84
4 yrs. '56-'60	4,137,793	29½	15,239,709	14,075,954	4,745,656	18,821,610	3.96	1.33	5.29
4 yrs. '60-'64	3,853,352	2½	13,807,524	12,723,768	8,829,945	21,553,713	3.47	2.42	5.89
4 yrs. '64-'68	3,652,670	28	12,810,969	11,783,656	7,365,577	19,149,233	3.14	1.96	5.10
4 yrs. '68-'72	3,873,432	28½	13,928,731	12,859,328	8,741,567	21,580,895	3.31	2.25	5.56
4 yrs. '72-'76	3,702,831	24½	11,440,800	10,399,378	12,289,528	22,688,906	2.56	3.02	5.58
4 yrs. '76-'80	3,211,689	24½	9,813,938	8,910,650	14,267,876	23,178,526	2.11	3.37	5.48
4 yrs. '80-'84	2,970,931	26½	9,459,427	8,598,853	17,295,090	25,893,943	1.95	3.86	5.81
8 yrs. '52-'60	4,092,160	28	14,310,779	13,159,859	4,652,724	17,812,643	3.74	1.32	5.06
8 yrs. '60-'68	3,753,011	28½	13,309,247	12,253,712	8,097,761	20,351,473	3.30	2.19	5.49
8 yrs. '68-'76	3,788,131	26½	12,684,765	11,619,353	10,516,548	22,134,901	2.94	2.63	5.57
8 yrs. '76-'84	3,091,310	24½	9,636,682	8,754,761	15,781,483	24,536,234	2.03	3.64	5.67
16 yrs. '52-'68	3,922,568	28	13,610,013	12,706,785	6,375,767	19,082,552	3.53	1.75	5.28
16 yrs. '68-'84	3,439,721	25½	11,160,724	10,187,052	13,148,515	23,335,567	2.48	3.14	5.62
32 yrs. '52-'84	3,681,153	27	12,485,369	11,446,919	9,761,894	21,208,813	3.00	2.45	5.45

The great increase of population which has taken place within the period covered by the table has, of course, necessitated greatly increased consumption, and the comparison of the home production and the foreign importation, for successive periods, becomes of much interest. The table shows that the average annual consumption over the four successive periods of eight years each, increased as follows :

1852-3 to 1859-60,	Annual Consumption,	17,812,643	quarters.
1860-1 to 1867-8,	"	20,351,473	"
1868-9 to 1875-6,	"	22,134,901	"
1875-6 to 1883-4,	"	24,536,234	"

These amounts were supplied from home produce and importation as follows :

	HOME PRODUCTION.	IMPORTATION.
1852-3 to 1859-60,	13,159,859 quarters	4,652,784 quarters.
1860-1 to 1867-8,	12,253,712 "	8,097,761 "
1868-9 to 1875-6,	11,619,353 "	10,515,548 "
1875-6 to 1883-4,	8,754,751 "	15,781,483 "

Thus, over the first eight years, only one-fourth of the wheat consumed was obtained from foreign sources, whilst over the last eight years, nearly two-thirds of the entire consumption were imported. It is probable that the home produce will still decline, consequent chiefly on reduction of area under cultivation ; whilst with increase of population, imports must increase, and doubtless our supplies will be largely drawn from this continent.

Produce of Wheat and Indian Corn per acre, in the United States.

It has been stated that, excluding recent bad seasons, the average yield of wheat per acre of the old arable soils of Great Britain, is twenty-eight bushels. Comparing this yield with that of the United States, as shown in Table XII., we find, on the authority of the U.S. Census Bureau, that the general average of localities and years is 11.9 bushels per acre ; a yield which is not equal to that of the continuously unmanured plot at Rothamsted, and which is considerably less than half the average yield of Great Britain under ordinary cultivation. This may be partly due to a shorter period of growth, and to rapid maturing, or in some localities to deficiency of rain ; but it is probably largely also due to want of sufficient labour to clean the land, and to consequent luxuriance of weeds.

Referring to the table, we find the general averages of the different sections of the States ranging from 15.1 bushels per acre in New England, to 7.3 bushels in the South Atlantic and Eastern Gulf States. Even the North-west and Minnesota, including much prairie land, give very meagre average produce for such rich soil. So long as wheat is grown on such lands under the conditions frequent, and indeed almost inevitable, in the case of new settlement,—that is, growing it year after year, with deficient cultivation, luxuriance of weeds, and the burning of the straw,—only low yields per acre can be expected. The result is due to the fact that, under such conditions, fertility is cheap and labour dear. But with increased density of population, more mixed agriculture must

be adopted. Stock must be kept, the farm kept freer from weeds, the straw used instead of being burnt, and the manure from it, and from the consumed food, returned to the land. Then, and not till then, will the fertility of the rich prairie soils be conserved, and not wasted, as is too often the case under the necessities of the first breaking up, and the sparse settlement, of the country. That your rich prairie soils can, and should, yield more produce than they do, is clear from the high yields obtained occasionally, under favourable conditions of cultivation.

TABLE XII.

Average yield per acre of Wheat and Indian Corn in the United States.

(From Signal Service Reports.)

Six years—1875–1880.

WHEAT—BUSHELS.							
	1875	1876	1877	1878	1879	1880	Gl. Av.
New England	16.1	13.9	16.8	15.3	15.0	13.3	15.1
Middle States	10.6	12.3	13.2	14.0	13.4	14.5	13.0
South Atlantic States	7.5	6.8	9.0	6.5	8.0	6.2	7.3
East Gulf States	9.0	6.7	7.2	7.1	8.1	5.6	7.3
West Gulf States	14.8	11.5	11.1	13.2	7.7	7.7	11.0
Tennessee and Ohio Valley	9.5	10.5	12.8	13.0	16.3	14.1	12.7
Upper Lake Region	13.7	10.2	16.1	15.2	15.8	13.5	14.1
North West	7.5	9.5	14.8	12.2	13.1	12.5	11.6
Minnesota	17.0	8.5	18.5	12.0	12.3	13.2	13.6
California	11.0	13.0	9.5	17.0	14.0	16.0	13.4
Average	11.7	10.3	12.9	12.6	12.4	11.7	11.9

INDIAN CORN—BUSHELS.							
	1875	1876	1877	1878	1879	1880	Gl. Av.
New England	34.0	35.8	35.9	36.5	32.2	32.9	34.6
Middle States	32.2	29.2	28.7	28.7	29.4	32.9	30.2
South Atlantic States	12.0	11.5	11.3	11.4	10.7	10.2	11.2
East Gulf States	15.0	13.3	13.2	12.1	14.3	13.4	13.6
West Gulf States	21.4	23.2	22.6	24.2	15.9	24.0	21.9
Tennessee and Ohio Valley	32.1	31.4	29.4	29.2	31.9	29.7	30.6
Upper Lake Region	27.0	31.6	23.3	37.4	38.1	36.5	32.3
North West	35.7	28.7	31.2	31.1	36.2	30.8	32.3
Minnesota	29.2	25.4	29.0	38.1	35.0	35.0	32.0
California	36.3	33.0	30.0	34.5	28.0	32.0	32.3
Average	27.5	26.3	25.5	28.3	27.2	27.7	27.1

Turning to Indian Corn, Table XII. shows that the yield of that cereal is very much higher than that of wheat; and the yield of nitrogen per acre in those corn crops would doubtless be much greater than in the wheat crops of the same localities. This is probably in part due to the high condition of the soil under which the crop is generally grown, corn generally following clover in the rotation. It is, however, doubtless in part due to the growth of corn extending much further into the late summer and autumn, the period during which nitrification is the most active in the soil, and when therefore the supply of nitrates to the plant will be greater under the same conditions of soil than in the case of wheat. This would be a very interesting subject for investigation, in the field and in the laboratory, tracing the nitrogen at various periods in the soil, in the plant, and in the drainage waters.

Produce of various crops per acre, in Manitoba.

The following table (XIII.) gives estimates of the yield of various crops on some Manitoba prairie soils:

TABLE XIII.

Estimates of the yield of various Crops in Manitoba.

Summary of Statistical Returns—seven years, 1876–1882.

Quantities in bushels per acre.

	1876	1877	1878	1879	1880	1881	1882	General Average.
Wheat	32	27	26	27	29	30	32	29
Barley.....	42	41	36	38	41	40	37	39
Oats.....	51	60	60	58	58	59	51	57
Rye	—	30	30	40	40	35	—	35
Peas	32	32	34	32	38	38	—	34
Potatoes	229	304	308	302	318	320	278	294

The above estimates are founded on the reports of numerous farmers, and it is seen that the average yield of wheat for seven years (1876–1882) is assumed to be twenty-nine bushels. This is, however, doubtless too high, even for exclusively virgin prairie soils, under the condition of cultivation incident to new settlement; and the result is probably accounted for by the fact that the records come chiefly from the more intelligent and better farmers. From returns since supplied to me from the Department of Agriculture at Ottawa, the average produce of wheat in Manitoba was, in 1880, 20.1 bushels, and in 1882, 24.0 bushels, instead of 29 and 32 bushels as above; whilst the average produce in 1883 is estimated at 21.8 bushels.

Amounts of Nitrogen and Carbon in various Soils.

In connection with this subject of the average yield of wheat of different countries, it will be of interest to contrast the condition of soils of very different history, as to their percentage of nitrogen, and, so far as we are able, of carbon also.

Table XIV. (see next page) shows the characters in these respects of exhausted arable soils, of newly laid down pasture, and of old pasture soils, at Rothamsted; of some other old arable soils; of some Illinois and Manitoba prairie soils; and lastly, of some very rich Russian soils.

From these results there can be no doubt that a characteristic of a rich virgin soil, or of a permanent pasture surface-soil, is a relatively high percentage of nitrogen and of carbon, and a high relation of carbon to nitrogen. On the other hand, a soil that has long been under arable culture is much poorer in these respects; whilst an arable soil under conditions of known agricultural exhaustion shows a very low percentage of nitrogen and of carbon, and a low relation of carbon to nitrogen.

Finally, it has been maintained by some that a soil is a laboratory, and not a mine. But not only the facts ascertained in our own and in other investigations, but the history of agriculture throughout the world, so far as we know it, clearly show that a fertile soil is one which has accumulated within it the residue of ages of previous vegetation, and that it becomes infertile as this residue is exhausted; and enormous as are the accumulations in the prairie lands of the American continent, it is still desirable to postpone, rather than to accelerate, the time of their exhaustion.

TABLE XIV.

Nitrogen and Carbon in various soils.

	Date of Soil Sampling.	(1) In Dry Sifted Soil.			Authority.
		Nitrogen.	Carbon.	Carbon to 1 Nitrogen.	

ROTHAMSTED ARABLE AND GRASS SOILS.					
		Per cent.	Per cent.	Per cent.	
Roots, 1843-'52; Barley, 1853-'5;	April, 1870	0.0934	.....	.....	Rothamsted.
Roots, 1856-'69; Mineral Manures	October, 1865	0.1119	1.039	9.3	"
Wheat, 1843-'4, and each year since;	October, 1881	0.1012	1.079	10.7	"
Mineral Manures	March, 1868	0.1202	.....	.....	"
Barley, 1852, and each year since;	March, 1882	0.1124	1.154	10.3	"
Mineral Manures	February, 1882	0.1235	.....	.....	"
Arable laid down to grass (Ten-	February, 1882	0.1509	.....	.....	"
acres), Spring, 1879	November, 1881	0.1740	.....	.....	"
Arable laid down to grass (Barn-	January, 1879	0.2057	2.412	11.7	"
field), Spring, 1874	September, 1878	0.1943	2.403	12.4	"
Arable laid down to grass (Apple-	Feb. & March, 1876	0.2466	3.377	13.7	"
tree field), Spring, 1863					
Arable laid down to grass (Dr. Gil-					
bert's meadow), Spring, 1858					
Arable laid down to grass (High-					
field), Spring (?), 1838					
Very old grass land (The Park)					

VARIOUS ARABLE SOILS IN GREAT BRITAIN.					
Mr. Prout's Farm; Broadfield—	.....	0.170	.....	.....	Voelcker.
surface					
Mr. Prout's Farm; Blackacre—	.....	0.107	.....	.....	"
surface					
Mr. Prout's Farm; Whitemoor—	.....	0.171	.....	.....	"
surface					
Wheat Soil—Midlothian .....	.....	0.22	.....	.....	Anderson.
" Eastlothian .....	.....	0.13	.....	.....	"
" Perthshire .....	.....	0.21	.....	.....	"
" Berwickshire .....	.....	0.14	.....	.....	"
Red Sandstone Soil—England .....	.....	0.18	.....	.....	Voelcker.

UNITED STATES AND CANADIAN PRAIRIE SOILS.					
Illinois, U. S., No. 1 .....	.....	0.30	.....	.....	Voelcker.
" " No. 2 .....	.....	0.26	.....	.....	"
" " No. 3 .....	.....	0.33	.....	.....	"
" " No. 4 .....	.....	0.34	.....	.....	"
Portage la Prairie, Manitoba—sur-	.....	0.247	.....	.....	Rothamsted.
face					
Saskatchewan district, N. W. Terri-	.....	0.303	.....	.....	"
tory—surface					
Forty miles from Fort Ellice, N. W.	.....	0.250	.....	.....	"
Territory—surface					
Niverville, Manitoba—1st 12 inches ...	.....	0.261	3.42	13.1	Rothamsted.
Brandon " " .....	.....	0.187	2.66	14.2	"
Selkirk " " .....	.....	0.618	7.58	12.3	"
Winnipeg " " .....	.....	0.428	5.21	12.2	"

RUSSIAN SOILS.					
No. 1—12 inches .....	.....	0.607	.....	.....	C. Schmidt.
No. 2—8 " .....	.....	0.467	.....	.....	"
No. 3—5 " .....	.....	0.198	.....	.....	"
No. 4—6 " .....	.....	0.130	.....	.....	"
No. 5—11 " .....	.....	0.305	.....	.....	"
No. 6—17 " .....	.....	0.281	.....	.....	"
No. 7—9 " .....	.....	0.409	.....	.....	"

(1) Calculated on soil dried at 100 C.

RESULTS OF EXPERIMENTS AT ROTHAMSTED,
ON THE
GROWTH OF BARLEY,

FOR MORE THAN THIRTY YEARS IN SUCCESSION
ON THE SAME LAND;

BEING

A LECTURE DELIVERED JUNE 29, 1886,

AT THE

ROYAL AGRICULTURAL COLLEGE,
CIRENCESTER,

BY

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Introduction.

In my lecture last year I gave an account of the experiments at Rothamsted on the growth of wheat for more than forty years in succession on the same land, without manure, with farm-yard manure, and with a great variety of artificial manures.

Attention was directed to the fluctuations in the amounts of produce from year to year, and to the average yield per acre over the earlier, the later, and the total period of the experiments, under each of the very varying conditions as to manuring.

The results of collateral investigations were also adduced.

For example, the increased assimilation and yield of carbon per acre in the crop, for a given amount of nitrogen supplied in manure, and the connection between carbon-assimilation, nitrogen-accumulation, and chlorophyll-formation, were shown. The proportion of the nitrogen supplied in the manure, which was respectively recovered in the increase of the crop, lost by drainage, or accumulated as crop-residue in the surface soil, was pointed out. The influence of exhaustion, or of full supply of the mineral constituents, on the mineral composition of the crop was shown; the general result being that whilst the amounts taken up by the entire plant, as represented by the quantities contained in the total produce, corn and straw together, varied considerably according to the supply within the soil, the amounts accumulated in the final and definite product, the grain, were under otherwise equal conditions nearly identical.

The influence of season was illustrated by the results obtained in the best and the worst seasons of the forty years. The general accordance of the Rothamsted results with those obtained on other soils and in other localities was next pointed out, and it was shown that at Woburn,

as at Rothamsted, when nitrogen was supplied as ammonium-salts, or as nitrate of soda, for wheat or barley, comparatively little of that which was not recovered in the immediate increase of crop, was recovered in the succeeding crops.

Leaving the experimental results, attention was directed to the average yield of wheat per acre in the United Kingdom over a period of 32 years. It was shown how greatly the area under the crop had diminished during that period, but that our yield per acre was greater than that of any other wheat growing country, and very much greater than that of the chief exporting countries, such as the United States, Canada, or India; and very much greater also than in most of the European countries where peasant proprietors or small holdings prevail.

The consideration of these facts naturally led to a consideration of the characteristic differences, in some important respects, of old arable soils, of pasture soils, and of prairie and other virgin soils. It was shown that a fertile soil was one which had accumulated within it, the residue of ages of previous vegetation, and that it becomes infertile as that residue is exhausted. Finally, it was concluded that it was extent of area, and cheap fertility, not good cultivation, against which the British wheat grower had to contend.

In the present lecture I propose to bring before you the results obtained at Rothamsted, on the growth of barley, not for more than forty years, but for thirty-four years in succession on the same land. The collateral investigations in connection with barley are not so numerous, or of such general interest or importance, as those to which attention was called in the case of wheat, but I shall be able to illustrate the influence of exhaustion, manures, and variations of season, on the amounts of produce, and to some extent on the composition of the crop. In conclusion, I shall adduce some statistics relating to our area under the crop, to the amount of our imports, and to the sources whence they are derived.

Barley, like wheat, is a member of the great gramineous family of plants, to which we owe so many, and such important economic products. In our own country and climate, barley comes second to wheat in importance among the cereal crops we cultivate; though, in the north, oats gain in relative consideration. The average area under *barley* in the United Kingdom is, however, only about four-fifths as great as that under wheat; and we shall see that it, like the area under wheat, has of late years diminished.

In countries with warmer and longer summers another gramineous grain crop, Indian corn, or maize, comes into prominence; and in warmer countries still grows the sugar cane. Indeed it is to this family that we owe our chief *starch*- and *sugar*-yielding crops; and it is somewhat remarkable that the plants which, at any rate in temperate climates, come next in importance as starch- and sugar- yielding crops, should belong to such widely different orders as the *Solanææ* giving us the potato, and the *Chenopodiaceæ* giving the sugar beet, mangel wurzel, &c., whilst the organs, or parts of the plants, which yield the

products are also widely different. In each case, however, it is the store of reserve material which the plant has laid up for reproduction which we turn to economic account.

But not only does the gramineous family provide us with our chief starch and sugar yielding crops, but it contributes a large proportion of the natural and cultivated herbage, upon which animals of use to man are fed over very large portions of the globe.

Although *wheat* and *barley* are thus closely allied botanically, and they have, moreover, in some respects very similar requirements as cultivated crops, yet it will be found that there are distinctions as well as similarities which it is important to recognise.

To refer to one or two points of distinction which obviously must have an influence on the results obtained in experiments on the growth of the two crops, and which must be borne in mind in their interpretation, it may be mentioned that, in our own country and climate at any rate, wheat is almost invariably sown in the autumn, whilst barley is as generally not sown until the spring.

Thus, wheat has four or five months for root-development, and for gaining possession of range of soil, before barley is sown. Under these circumstances, too, the conditions of soil most suitable to the two crops are very different. For wheat a comparatively heavy soil is adapted, and a fine tilth, encouraging superficial root-development, is not desirable. For barley, on the other hand, a comparatively light soil is more appropriate, and a fine tilth is of great importance. In other words, with the characteristic habit of growth of the plant, and the short period at its command for root-development, a very permeable surface-soil is a desideratum.

In these facts we have the indication that wheat acquires a much greater root-range, and consequently a command of the resources of a more extended range of both soil and subsoil; whilst barley must, in a greater degree, be dependent on the supplies within the surface-soil, and so be the more susceptible to the influence of the exhaustion, or the supplies, within the surface-soil.

Bearing these various points in mind, we may now turn to the results of long-continued field-experiments on the growth of barley, by different manures, and in different seasons, and to the evidence of collateral Laboratory investigations as to its composition.

The Rothamsted Field Experiments on Barley.

The Rothamsted Field Experiments on Barley were commenced in 1852, that is eight years later than those on wheat, but at the same time as that at which the arrangements of the plots in the Experimental Wheat Field devoted to chemical or artificial manures became more systematic and permanent.

The barley crop of last year, 1885, was the thirty-fourth in succession on the same land, and the thirty-fifth crop is now growing. There are nearly thirty experimental plots. Two have been unmanured from the commencement. One has received farm-yard manure every year, or rather one-half of it has, for after twenty years the plot was

divided, one half being still annually manured as before, and the other half then left unmanured, to test the effects of the unexhausted residue of the twenty years' previous applications of farm-yard manure. The other plots have annually received artificial manures, for the most part the same year after year, from the commencement; but there have been a few changes, some of which will be explained as we proceed.

Results without Manure, and with Farmyard Manure.

The results to which I shall first direct your attention are those obtained *without manure*, and with *farmyard manure*. Table I. (p. 5) gives the produce of grain per acre in each year, and also the average produce over selected series of years, and over the whole period of 32 years, to 1883 inclusive.

The first column of the Table gives the produce without manure. Columns 2 and 3 give the produce by farmyard manure for the first twenty years (1852-1871) over the whole plot, and for the next twelve years (1872-1883). Column 2 gives the produce on the half of the plot on which the application was still continued, and column 3 that on the other half where the application was discontinued after the first twenty years, showing therefore the effects of the residue of the previous applications. Column 4 shows, for the last twelve years, the excess of produce on the plot where the application was continued over that where it was discontinued; and the last two columns show the increase over the unmanured produce, first by farmyard manure continuously applied, and secondly by the residue of the applications of the first twenty years.

First referring to the produce *without manure*, it is seen that in two years, the third and fourth, the yield was over thirty bushels per acre; in six years during the first thirteen, the produce was between twenty and thirty bushels, but it never afterwards reached twenty bushels, and in twenty-four out of the thirty-two years the yield was less than twenty bushels; in two of these it amounted to only ten, and in one (1879), to only $6\frac{1}{2}$ bushels.

There was thus a very great variation in the amount of produce without manure from year to year according to season. A glance at the figures, and especially at the average produce over successive series of years, as given at the foot of the Table, shows, however, that independently of these fluctuations due to season, there was a progressive decline due to exhaustion; though the last four years gave a higher average than any other four in the last sixteen years.

It may be observed that without manure there is a decline in the produce of barley grain of 31·4 per cent. over the second sixteen years compared with the first sixteen; and that this rate of decline is considerably greater than was found in the case of wheat. This result is doubtless due to the shorter period of growth, and the greater dependence on the surface soil, in the case of the barley; and hence exhaustion is the sooner manifested.

We now turn to the produce by *farmyard manure*. As without manure, there is very great fluctuation from year to year according to

TABLE I

Barley 32 years in succession on the same land, Hoosfield, Rothamsted.

Produce—Without Manure, and with Farm-yard Manure.

DRESSED GRAIN PER ACRE, BUSHEL.

	Un-manured every year	FARM-YARD MANURE				
		Every year 1852-53	20 years, 1852-71 Un-manured 1872-83	Continuous + or - Un-manured after 20 years	+ Unmanured	
					Manured every year	Manured 20 years, Unmanured afterwards
	Plot 1-0	Plot 7-2	Plot 7-1		Plot 7-2	Plot 7-1
1852	27½	33			+ 52	
1853	25½	36½			+ 10½	
1854	35	56½			+ 21½	
1855	31	50½			+ 19½	
1856	13½	32½			+ 18½	
1857	26½	51½			+ 25½	
1858	21½	55			+ 33½	
1859	13½	40			+ 26½	
1860	13½	41½			+ 28½	
1861	16½	54½			+ 38½	
1862	16½	49½			+ 33½	
1863	22½	59½			+ 36½	
1864	24	62			+ 38	
1865	18	52½			+ 34½	
1866	15½	53½			+ 37½	
1867	17½	45½			+ 28½	
1868	15½	49½			+ 28	
1869	15½	46½			+ 31½	
1870	13½	47½			+ 34	
1871	16½	54½			+ 37½	
1872	10½	38½	38½	+ 0½	+ 29½	+ 28
1873	14	54½	47½	+ 6½	+ 40½	+ 39½
1874	17½	64½	46½	+ 18	+ 46½	+ 38½
1875	12½	45½	32½	+ 12½	+ 32½	+ 20
1876	12½	45	31	+ 14	+ 32½	+ 18½
1877	17½	52	36	+ 16	+ 34½	+ 18½
1878	10	46½	21½	+ 24½	+ 36½	+ 11½
1879	6½	36½	16½	+ 20	+ 30½	+ 10½
1880	18½	65½	41½	+ 23½	+ 46½	+ 22½
1881	17½	53½	29½	+ 24	+ 35½	+ 11½
1882	18½	60½	35	+ 25½	+ 42½	+ 16½
1883	16½	58½	35½	+ 23	+ 42½	+ 19½

AVERAGES

4 yrs. 1852-55	29½	43½			+ 14½	
" 1856-59	16½	44½			+ 26	
" 1860-63	17½	51½			+ 34½	
" 1864-67	16½	53½			+ 34½	
" 1868-71	15½	48			+ 32½	
" 1872-75	13½	50½	41½	+ 9½	+ 37½	+ 27½
" 1876-79	11½	45	26½	+ 18½	+ 39½	+ 14½
" 1880-83	17½	59½	35½	+ 24	+ 41½	+ 17½
10 yrs. 1852-61	22½	45			+ 22½	
10 " 1862-71	17½	51½			+ 34	
20 yrs. 1852-71	19½	49½	34½		+ 28½	
12 " 1872-83	14½	51½		+ 17½	+ 37½	+ 20
32 yrs. 1852-83	17½	49½	43		+ 31½	+ 25½
Last 12 yrs. P.C. + or - first 20 yrs.	- 27-7	+ 7-3	- 28-8			

season ; but instead of a gradual decline there is an obvious increase in the yield over the later years, due to the accumulation of the manure. There is, in fact, instead of a decline of 27·7 per cent., an increase of 7·3 per cent. over the last twelve years compared with the first twenty ; although the second period included a number of the worst seasons of the whole series of years.

In four of the thirty-two years the farmyard manure gave more than 60 bushels of barley per acre, in thirteen years between 50 and 60 bushels, in ten between 40 and 50 bushels, in five between 30 and 40 bushels, and in no case below 30 bushels. The average yield was, over the first twenty years $48\frac{1}{2}$ bushels, over the last twelve years $51\frac{3}{4}$ bushels, and over the thirty-two years $49\frac{1}{2}$ bushels, against $17\frac{3}{4}$ bushels without manure.

So much for the produce of barley obtained by the unusual application of fourteen tons of farmyard manure per acre per annum, for thirty-two years in succession. It is estimated that the manure supplied about 200 lbs. of nitrogen per acre per annum, or over twenty years 4,000 lbs. of nitrogen. It was further estimated that at the end of twenty years, not more than fourteen or fifteen per cent. of this large amount of nitrogen had been removed in the increase of crop. There must, therefore, have been a great accumulation of nitrogen, and other constituents, within the soil ; and analysis proved that this was the case. Indeed, it was calculated that, if there were no loss of nitrogen, by drainage, by evolution of free nitrogen, or otherwise, and if the accumulated residue were as available as that which had already been effective, the produce should be maintained at the level of that of the first twenty years for not far from 150 years more.

Let us see what was the result of stopping the application of manure on half the plot after the first twenty years ? This is shown in the lower division of the table. The second column shows the produce of the last twelve years, where the application was continued ; the third column where it was discontinued ; the fourth the excess yielded by the continuous application over that by the residue from previous applications. Lastly, the fifth column shows the increase over the unmanured produce, by the continuous application, and the sixth that by the residue.

Comparing the second and third columns, it is seen that there is a general tendency to increase in yield where the application of the farmyard manure was continued, and to decrease where it was discontinued. This result is brought prominently to view in column 4, which shows that the difference between the amount of produce gradually increases until during the last four of the twelve years, the *manure-residue* plot shows an average of about twenty-four bushels per acre per annum less than where the application was continued.

The averages at the foot of the table show that over the first twenty years, with the continuous application the yield was $48\frac{1}{2}$ bushels, whilst over the succeeding twelve years, it was, where the application was continued $51\frac{3}{4}$ bushels, but where it was discontinued

only $34\frac{3}{8}$ bushels; showing, therefore, an average annual deficiency under the influence of the residue only, of $17\frac{3}{8}$ bushels, or of 33·6 per cent.

Taking as the standard of comparison the unmanured produce (which, however, itself gradually declined), the last two columns show that over the three four-yearly periods of the last twelve years, the increase of produce was with the continued application $37\frac{1}{8}$, $33\frac{1}{2}$, and $41\frac{1}{4}$ bushels, but with the residue only $27\frac{5}{8}$, $14\frac{7}{8}$, and $17\frac{5}{8}$ bushels. Over the whole twelve years there was an average annual increase of $37\frac{3}{8}$ bushels with the continued application, and of only 20 bushels with the residue.

It may be observed that over the whole period of thirty-two years, the total produce (grain and straw together) was without manure less than one ton per acre per annum, whilst with the farmyard manure it was $2\frac{3}{4}$ tons, and in some years it reached from $3\frac{1}{4}$ to $3\frac{3}{4}$ tons.

To sum up in regard to the foregoing results—there was gradual exhaustion and reduction of produce without manure, and gradual accumulation and increase of produce with the annual application of farmyard manure. But when the application was stopped, although the effect of the residue from the previous applications was very marked, it somewhat rapidly diminished, notwithstanding that calculation showed an enormous accumulation of nitrogen as well as other constituents.

Indeed, determinations of nitrogen in the surface-soil, after the twenty years application of farmyard manure, showed it to be nearly twice as high as on the unmanured plot.

How then is the reduction of produce to be accounted for? The nitrogen of farmyard manure must obviously exist in very different conditions. That due to the urine of the animals will be the most rapidly available, that in the finely comminuted matter in the fæces will be much more slowly available, and that in the litter still more slowly available. Hence the small proportion that is at once effective, and the very large amount that accumulates within the soil in a very slowly available condition.

But the evidence at command leads to the conclusion that neither in the wheat field, nor in the barley field, does the accumulation within the soil account for the whole of the nitrogen supplied which is not recovered in the immediate increase of crop. Some is doubtless lost as nitrates by drainage, and some probably by evolution as free nitrogen. The fact of such losses is of considerable interest; but it is some consolation to believe that the loss will be proportionally very much less in ordinary farm practice, where the amounts of farmyard manure applied are much less, and where various crops, with different root-ranges, and different periods of accumulation, are grown.

Results without Manure, and with Artificial Manures.

We have next to consider—what is the character of the exhaustion induced by the growth of the crop without manure? and to what constituent, or constituents, of farmyard manure, its effects are mainly to be attributed? These points will be illustrated by the results given in Tables II. and III. (p.p. 8 and 9), which show the effects of various

TABLE II

Barley 34 years in succession on the same land, Hoosfield, Rothamsted.

Results showing the effects of exhaustion and Manures.

Dressed Grain per Acre, Bushels. Manure and produce per Acre per annum.

	SERIES 1				SERIES 2 300 lbs. Ammonium-Salts = 48 lbs. N.			
	Un- manured	Super- phosphate of Lime	Potassium Sodium, and Magnesium Sulphates	Mixed Mineral Manure (3 & 5 mixed)	Alone	And Super- phosphate of Lime	And Potassium Sodium and Magnesium Sulphates	And Mixed Mineral Manure (2 and 5 mixed)
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 1	Plot 2	Plot 3	Plot 4
1852	27½	28½	26½	32½	36½	38½	36	40½
1853	25½	33½	27½	35½	38½	40½	36½	38½
1854	35	40½	36½	42	47½	60½	50	60½
1855	31	36½	34½	37½	44½	47½	44½	48½
1856	13½	17½	16½	19½	25	29½	28½	31½
1857	26½	33½	32	39½	38½	56½	42½	57½
1858	21½	28½	24½	30½	31½	51½	34½	51½
1859	13½	19½	15½	19½	15½	34½	16½	34½
1860	13½	15½	15½	18½	26½	49½	38	49½
1861	16½	25	18½	29½	30½	55	39½	54½
1862	16½	21½	19½	25½	31½	48½	35½	47½
1863	22½	32½	27½	33	42½	61½	49½	56½
1864	24	30½	26½	33½	38½	58½	43½	55½
1865	18	22½	22	24½	29½	48½	33½	46½
1866	15½	22½	19½	24	27½	50½	27½	47
1867	17½	24½	17	20½	30½	44	33	43½
1868	15½	18½	14½	17½	20½	37½	25	34½
1869	15½	18½	18½	22½	27½	48	34½	49½
1870	13½	18	16½	18½	27½	41½	30½	38
1871	16½	20½	19½	25	36½	45½	38½	46½
1872	10½	15½	10½	14½	26½	39½	30½	36½
1873	14	19½	14½	20½	32½	50½	34½	46½
1874	17½	21½	17½	19½	23½	42½	30½	45½
1875	12½	14½	14½	17½	27½	37	29½	35½
1876	12½	16½	12½	15½	21	33½	23½	35½
1877	17½	22½	20½	23½	35½	43½	41½	50½
1878	10	12½	7½	11½	14½	31½	20½	33½
1879	6½	7½	6½	7½	15½	27½	16½	27½
1880	18½	28½	23½	30½	33½	55½	38½	54½
1881	17½	19½	17½	17½	33½	43½	37½	42½
1882	18½	21½	19	23½	34½	45½	39½	50½
1883	16½	22½	18½	24½	38½	49½	43½	52
1884	13½	17½	13½	14½	26½	29	31	42½
1885	9½	12½	7½	12½	15½	29	15½	32
AVERAGES								
4 yrs. 1852-55	29½	34½	31½	36½	42	46½	41½	47
" 1856-59	18½	24½	22½	27½	27½	42½	30½	43½
" 1860-63	17½	23½	20½	26½	32½	52½	36½	50½
" 1864-67	18½	25	21½	25½	31½	50½	34½	48½
" 1868-71	15½	19½	17½	20½	28½	43½	32½	42½
" 1872-75	13½	17½	14½	17½	27½	42½	31½	41½
" 1876-79	11½	15	11½	14½	21½	34½	25½	36½
" 1880-83	17½	23	19½	23½	36½	46½	39½	49½
8 yrs. 1852-59	24½	29½	26½	32½	34½	44½	36½	45½
" 1860-67	18	24½	20½	26	32½	51½	35½	49½
" 1868-75	14½	18½	15½	19½	27½	42½	31½	41½
" 1876-83	14½	19	15½	19½	28½	41½	32½	43½
16 yrs. 1852-67	21½	27½	23½	29½	33½	48	35½	47½
" 1868-83	14½	18½	15½	19½	28½	42	32	42½
32 yrs. 1852-83	17½	23	19½	24½	30½	45	33½	44½
P.C. Reduction and 16 yrs.	31.4	30.9	33.7	33.9	16.0	12.5	10.2	10.3

TABLE III

Barley 34 years in succession on the same land, Hoosfield, Rothamsted.

Results showing the effects of Exhaustion and Manures.

Dressed Grain per acre, Bushels. Manures and Produce per acre per annum.

	SERIES 3 275 lbs. Nitrate Soda = 43 lbs. N (1).				SERIES 4 1000 lbs. Rape Cake = 40 lbs. N (3)			
	Alone	Super-phosphate of Lime	Potassium Sodium and Magnesium Sulphates	Mixed Mineral Manure (3 and 8 mixed)	Alone	And Super-phosphate of Lime	And Potassium Sodium and Magnesium Sulphates	Mixed Mineral Manure (3 and 8 mixed)
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 1	Plot 2	Plot 3	Plot 4
1852	44½	43½	41½	45½	39½	36½	33½	38
1853	40½	42½	41½	44½	39½	36½	35½	40½
1854	56½	63½	51½	62½	60½	60½	56½	60½
1855	48	50½	47½	49½	48½	52½	48½	51½
1856	36½	31½	25½	37½	36½	37½	32½	35½
1857	49½	60½	49½	64½	64½	62½	60½	62½
1858	39½	56½	40½	56½	53½	67½	52½	57½
1859	21½	35½	20½	35½	38½	41	34½	36
1860	25½	43½	30½	46½	31½	36½	35½	40½
1861	35	55½	36½	55½	56½	56½	51½	53½
1862	31½	51	36½	48½	41	45	36	45½
1863	49	60½	54	59½	51½	55	53½	54½
1864	41½	56½	44½	56½	48½	51½	49½	53
1865	33½	47½	34½	48½	45	46½	46½	48½
1866	29½	50½	29½	50½	45½	47½	43½	46½
1867	29½	44½	32½	45	38½	45½	36½	42½
1868	37	44	37½	45½	37	35½	35½	36½
1869	32½	48½	32½	49½	42½	46½	43½	52½
1870	29½	46½	32½	44½	41½	41½	36½	43½
1871	39½	46½	36½	46	44	41½	46½	47½
1872	26½	36½	23½	32	30½	33½	27½	33½
1873	37½	49	33½	48½	45½	46½	44½	46½
1874	30½	53½	32	51½	47½	49½	45½	49½
1875	29½	38½	27½	42½	38½	42½	33½	44½
1876	19½	31½	22½	36½	36½	34½	31	35
1877	37½	46½	38½	49½	44½	42½	43½	47½
1878	15½	33½	20½	31½	27½	32	29½	32½
1879	13½	26½	16½	25½	27½	28½	26½	31½
1880	38½	57½	41½	59½	50½	55½	51½	54½
1881	34½	43½	36½	47½	41½	47½	40½	45
1882	34½	46½	36½	50½	44½	48½	44½	46½
1883	43½	53½	44½	54½	46	49	44½	48½
1884	34½	43½	33½	45½	40	43½	38½	40½
1885	17½	38½	21½	31½	28½	34	26½	32½

AVERAGES

4 yrs. 1852-55	47½	49½	45½	50½	47	48½	43½	47½
" 1856-59	36½	47½	34	48½	48½	49½	44½	47½
" 1860-63	35½	52½	39½	52½	45½	48½	43½	48½
" 1864-67	39½	49½	35½	50½	44½	47½	45½	48½
" 1868-71	31½	46½	32½	46½	41½	41½	40½	44½
" 1872-75	31	45	30½	43½	40½	43½	37½	43½
" 1876-79	21½	34½	24½	35½	34	34½	32½	36½
" 1880-83	37½	50	39½	53	45½	50½	45½	48½
8 yrs. 1852-59	42½	48½	39½	49½	47½	48	44½	47½
" 1860-67	34½	51½	37½	51½	44½	48	44½	48½
" 1868-75	31½	45½	31½	44½	40½	42½	39½	44½
" 1876-83	29½	42½	32	44½	39½	42½	39	42½
16 yrs. 1852-67	38½	50	38½	50½	46½	48	44½	47½
" 1868-83	30½	44	31½	44½	40½	42½	39½	43½
32 yrs. 1852-83	34½	47	35½	47½	43½	45½	41½	45½
P.C. Reduction	20.3	12.0	17.8	11.6	12.7	11.5	11.8	9.4
2nd 16 yrs.								

(1) 6 yrs. 1852-7, Amm. Salts 400 lbs.; 10 yrs. 58-67, 200 lbs.; 1868 and since, 275 lbs. Nitrate soda.
 (3) 6 yrs. 1852-71 Rape Cake 2000 lbs., and since 1000 lbs.

purely mineral manures, of purely nitrogenous manures, and of combinations of the two.

Results are given for sixteen plots, arranged in four series of four plots each, and for each plot the produce—dressed grain per acre—is given for thirty-four years in succession.

Series 1 comprises four plots, without any nitrogenous manure, namely—

- Plot 1.—Without manure.
- „ 2.—Superphosphate of lime alone.
- „ 3.—Sulphates of potash, soda, and magnesia.
- „ 4.—Superphosphate, and sulphates of potash, soda, and magnesia.

Series 2 comprises four plots, with the same four conditions as to mineral manures as Series 1, and ammonium salts supplying 43 lbs. of nitrogen per acre, per annum, in addition.

Series 3, the same four conditions as to mineral manure, with for six years 86 lbs., and for ten years 43 lbs. of nitrogen per acre per annum as ammonium salts, and for the last eighteen years 43 lbs. as nitrate of soda.

Series 4, the same four conditions as to mineral manure, with 2,000 lbs. rape cake per acre per annum, in the first six years; and 1,000 lbs. each year since.

It may be mentioned that 1,000 lbs. rape cake will, on the average, contain 48 to 50 lbs. of nitrogen, or rather more than in the amounts of ammonium-salts, or nitrate used, though probably not more is rendered available within the years of application, but there will obviously be accumulation, and some cumulative action from year to year.

Time will not allow me to call your attention in any detail to the produce of individual years, but you will observe that under all conditions of manuring, whether without nitrogenous supply as in Series 1, or with it, in the different forms and combinations, as in the other Series, there is great fluctuation from year to year, according to season. Thus, without manure the produce ranges from 35 bushels in 1854, to only $6\frac{1}{2}$ bushels in 1879; with a full mineral manure (plot 4, Series 1) from 42 bushels in 1854 to $7\frac{1}{2}$ bushels in 1879; with the full mineral manure and ammonium salts (plot 4, Series 2) = 43 lbs. nitrogen, from $60\frac{1}{2}$ bushels in 1854 to $27\frac{3}{8}$ in 1879.

As in the cases of Series 3 and 4, more nitrogen was applied during the first six years than afterwards, the comparison of the produce in individual years at the beginning and at the end of the period have not quite equal significance; but it may be observed that with the full mineral manure and ammonium salts at first, and nitrate of soda afterwards (plot 4, Series 3), the produce varied from nearly 65 bushels in 1857 to $25\frac{1}{2}$ bushels in 1879; and lastly, with the full mineral manure and rape cake it ranged from $62\frac{1}{2}$ bushels in 1857 to $31\frac{1}{8}$ bushels in 1879.

Looking to the average produce of each of the eight four-yearly periods, it is seen that, under all conditions of manuring, even in the case of the rape cake with its annual accumulation, there is a general

tendency to reduction in produce from the first to, and especially in, the seventh period, 1876 to 1879; but there is as uniformly an increase over the eighth period, 1880 to 1883. There is in these facts clear evidence that the previous reduction was, independently of exhaustion in individual cases, mainly due to the seasons.

The bottom line of the Tables, which shows the percentage reduction in the amount of produce over the second 16 years compared with the first 16, enables us to discriminate in some degree between the effects of exhaustion and those of season.

It is seen that the four plots of Series 1 show a reduction over the second 16 years from about 31 to 34 per cent., or more than twice as much as in the case of either of the other Series. There is here evidence that in the case of Series 1, without nitrogenous manure, much of the reduction over the second half of the period was due to nitrogen-exhaustion.

In Series 2, with ammonium salts, there is 16 per cent. reduction on plot 1, where the ammonium salts are used alone, and only from 10 to 12 per cent. where mineral manures are used in addition.

In Series 3, with nitrate of soda, there is a reduction of 20 per cent. where the nitrate is used without mineral manure, of nearly 18 per cent. where it is used with potash, soda, and magnesia, but without phosphate (plot 3), and of only about 12 per cent. where phosphates were used in addition to the nitrate.

Lastly, in Series 4, with rape cake, which contains a considerable amount of mineral matter, there is a reduction of only 12·7 per cent. where it is used alone, of less where any mineral manure is used in addition, and of only about 9½ per cent. where a full mineral manure is also used.

As already intimated, that there should be any reduction in the yield over the second half of the period where rape cake, with its annual residue and accumulation, is used, is evidence that part of the reduction is due to an average of less favourable seasons over the later period. But that there should be the greatest reduction in Series 1, where no nitrogen is supplied, is evidence of nitrogen-exhaustion under those conditions; and that within Series 2 and 3 respectively there should be the greatest reduction, where the ammonium salts or nitrate are used without phosphates, is evidence of phosphoric-acid exhaustion in those cases.

Leaving the results relating to the produce of each individual year, or of limited series of years, as given in Tables II. and III., a general view of the effects of the sixteen different conditions as to manuring is conveniently obtained in the *Summary Table IV.* (p. 12). There is there given the average produce over the thirty-two years on each of the sixteen plots. The first column gives the results for the four plots of Series 1, without nitrogenous manure; the second column those for Series 2, with ammonium salts equal to 43 lbs. nitrogen per acre per annum; the third those for Series 3, with nitrate of soda; and the fourth those for Series 4, with rape cake. The upper division of the Table gives,

for each plot, the average produce of grain per acre in bushels; the middle division, the average produce of straw in lbs.; and the lower division, the average total produce (corn and straw together) in lbs.

TABLE IV.

Barley 32 years in succession on the same land—Hooofield, Rothamsted.

SUMMARY.

Showing the effects of exhaustion and manures.

	No Nitro- genous Manure	200 lbs. Am. Salts = 43 lbs. N	275 lbs. N. Soda (1) = 43 lbs. N	1000 lbs. R. Cake (2) = 49 lbs. N
DRESSED GRAIN per acre. Bushels				
Without Mineral Manure	17½	90½	84½	43½
Superphosphate	23	45	47	45½
Sulphates Potash, Soda, and Magnesia ...	19½	83½	85½	41½
Superphosphate and Sulphate Potash, Soda, and Magnesia	24½	44½	47½	45½
STRAW, per acre. Lbs.				
Without Mineral Manure	1198	1909	2246	2789
Superphosphate	1293	2827	3127	2853
Sulphates Potash, Soda, and Magnesia ...	1170	2151	2455	2792
Superphosphate, and Sulphates Potash, Soda, and Magnesia	1380	3019	3348	3065
TOTAL PRODUCE (GRAIN and STRAW), per acre. Lbs.				
Without Mineral Manure	2136	3649	4189	5249
Superphosphate	2584	5374	5791	5532
Sulphates Potash, Soda, and Magnesia ...	2278	4063	4490	5175
Superphosphate, and Sulphates Potash, Soda, and Magnesia	2739	5574	6042	5667

(1) Ammonium-Salts = 86 lbs Nitrogen first 6 years, = 43 lbs next 10 years; Nitrate Soda = 43 lbs Nitrogen last 16 years. (2) 2000 lbs Rape Cake first 6 yrs. 1000 lbs since.

Referring first to the results on the four plots without nitrogenous manure, as given in the first column of the Table, it is seen that plot 2, with superphosphate of lime, and plot 4, with superphosphate and salts of potash, soda and magnesia, give considerably more produce than plot 3, with the potash, soda, and magnesia, without phosphate. There is more of straw, as well as grain, and of course, therefore, of total produce, with than without the phosphate. There is, indeed, very marked effect by phosphatic manure, and very little by the alkalies.

The second column, with the same four conditions as to mineral supply, but with, in each case, 43 lbs. of nitrogen per acre per annum as ammonium salts, shows a very great increase. Even with the ammonium salts alone there is a great increase; there is somewhat more on plot 3, where the alkalies are also applied, but very much more still on plots 2 and 4, where phosphates are also used.

The third column shows that with a larger amount of nitrogen supplied in the first six years, and with nitrate of soda instead of ammonium salts in the later years, there is still greater increase; and again, the increase is by far the greater where the superphosphate is used.

The four plots of Series 4, with the rape cake, show a much greater uniformity of result with the different mineral manures. Still the two phosphate plots (2 and 4) give more produce than the two without phosphate. Referring to the produce of grain in illustration, it is seen that plots 1 and 3 without phosphate give considerably more produce than the same plots (1 and 3), in either Series 2 with the ammonium salts, or in Series 3 with the nitrate of soda. The explanation of this is that the rape cake itself contains phosphates. On plots 2 and 4, on the other hand, where phosphates are added, there is nearly as much produce in Series 2 with the ammonium salts, and more in Series 3 with the nitrate, than in Series 4 with the rape cake.

Thus, then, whilst there is evidence that the phosphate of the rape cake was effective when none was otherwise supplied, when it was so applied in addition there was more effect with the nitrate, with its more rapidly available nitrogen, than with the rape cake, with its greater actual amount of nitrogen, but in a less rapidly available condition.

Comparing the produce of plot 2 with superphosphate without potash, with that of plot 4 with superphosphate, and salts of potash, soda and magnesia in addition, it is remarkable that, both in Series 2 with the ammonium salts, and in Series 3 with nitrate of soda, there is over the whole period of thirty-two years almost identically the same amount of barley grain without as with the potash. There is, however, rather more straw and total produce with than without the potash. Thus we have, with the ammonium salts, an average of forty-five bushels without potash, and $44\frac{7}{8}$ bushels with potash; and with the nitrate of soda 47 bushels without, and $47\frac{1}{2}$ bushels with potash. Of straw, however, there is, with the ammonium salts, an average of 2,827 lbs. without, and 3,019 with the potash; and on the nitrate plots 3,127 lbs. without, and 3,348 lbs. with potash.

It will afterwards be seen that where nitrogen and phosphoric acid were liberally supplied without potash, the available potash of the soil itself became deficient; though this deficiency was to the last scarcely at all manifested in the produce of grain. It is obvious, however, that with gradual reduction in the amount of plant, the yield of grain must in time diminish.

So much for the influence on the barley crop, of different conditions of manuring, each continued for more than thirty years on the same plot, and in a field of somewhat heavy loam, with a raw clay subsoil, and chalk below, giving good natural drainage.

It is seen that nitrogenous manures alone had much more effect than mineral manures alone. It was obvious, therefore, that the exhaustion induced by the continuous growth of the crop was characteristically that of nitrogen.

Both with and without nitrogenous supply phosphates were more effective than potash salts, showing that the available store of phosphoric acid in the soil became deficient sooner than that of potash. With the shorter period of growth of barley than of wheat, and its greater proportion of surface-rooting, both nitrogenous and mineral exhaustion

are sooner developed ; and so far as mineral exhaustion is concerned, the available supply of phosphoric acid was sooner exhausted than was that of potash. Indeed, in ordinary agricultural practice, it is clearly established that superphosphate is more effective with the spring-sown than with the autumn-sown cereals.

Influence of Season on the Amounts of Produce.

It has been seen that there were, under all conditions of manuring, very great variations in the amount of produce from year to year according to season. The extent and character of the influence of season will be brought prominently to view by comparing the produce of the best and the worst seasons of the thirty-two, and comparing the characters of the seasons themselves.

Tables V. and VI. illustrate these points. Table V. (p. 15) gives the produce of grain, the weight per bushel of the grain, the produce of straw, and the total produce (corn and straw together), of six very different conditions as to manuring in each of the best two seasons, and in the worst season of the whole series. There is also given the deficiency of produce in the bad season, compared with that in each of the two good seasons.

For wheat, 1863 was the best season of the thirty-two—indeed of the forty—of its growth. For barley, 1863 was also a very good year for both grain and straw ; but it was not so good for such a variety of manures as were 1854 and 1857, which (in the Table) are adopted as the best seasons.

For almost all conditions of manuring, 1854 was the season of the highest total produce, corn and straw together ; that is it was the season of the greatest luxuriance or vegetative activity. But 1857 was, especially for the highest manuring, the one of the highest produce of grain, and of the highest quality or maturity of grain, as evidenced by the weight per bushel. Thus 1854 was the highest for luxuriance, and 1857 the highest for the maturation of the crop.

As for wheat, so for barley, 1879 was decidedly the worst season of the thirty-two.

The plots selected for illustration are those without manure, with farmyard manure, with mixed mineral manure alone, with mixed mineral manure and ammonium salts, with mixed mineral manure and nitrate of soda, and with mixed mineral manure and rape cake.

It is not necessary to detain you with any detailed consideration of the results—the figures speak for themselves. The lower division of the Table shows that under each of the six very different conditions as to manuring, 1854 yielded a much higher total produce (grain and straw together) than 1857. But the upper division shows that, notwithstanding the less amount of plant, 1857 gave in most cases nearly as much grain as 1854, and in two cases—those with the highest nitrogenous manuring—and both years were within the first six when the larger amounts were applied), 1857 gave more grain than 1854. The weight per bushel of the grain was also higher in 1857, on all the plots where nitrogenous manures were used.

The contrast between the produce in these two very different good years, and that in the worst season 1879, is very striking, the difference amounting in several cases to as much as the average crop of the country.

TABLE V

Barley, year after year on the same land, Hoosfield, Rothamsted.

Produce of the two best seasons, 1854 and 1857; of the worst season, 1879; and average of 32 years, 1852-1883

Plots	DESCRIPTION OF MANURES; QUANTITIES PER ACRE.	Best Seasons		Worst Season 1879	1879 + or—		Average 32 Years
		1854	1857		1854	1857	
DRESSED GRAIN per acre, BUSHELS							
1o	Unmanured	35	26½	61	-28½	-19½	17½
7-2	Farm-yard Manure	56½	51½	36½	-19½	-14½	49½
4o	Mixed Mineral Manure, alone... ..	42	39½	7½	-34½	-32½	24½
4a	Mix. Min. Man. and 200 lbs Amm. Salts=48 lbs N	60½	57½	27½	-33½	-30	44½
4aa	" " " and 275 lbs Nit. Soda=43 lbs N ...	62½	64½	25½	-37½	-39½	47½
4c	" " " and 1000 lbs Rape Cake=49 lbs N	60½	62½	31½	-29½	-31½	45½
WEIGHT PER BUSHEL OF DRESSED GRAIN. LBS							
1o	Unmanured	53·6	52·0	48·8	-4·8	-3·2	52·2
7-2	Farm-yard Manure	53·9	54·2	50·5	-3·4	-3·7	54·3
4o	Mixed Mineral Manure, alone... ..	54·0	53·7	50·4	-3·6	-3·8	53·2
4a	Mix. Min. Man. and 200 lbs Amm. Salts=48 lbs N	54·3	54·8	50·2	-4·1	-4·6	54·2
4aa	" " " and 275 lbs Nit. Soda=43 lbs N ...	52·1	53·9	49·8	-3·8	-4·1	53·8
4c	" " " and 1000 lbs Rape Cake=49 lbs N	52·8	54·1	49·6	-3·2	-4·5	53·9
STRAW per acre, LBS.							
1o	Unmanured	2442	1425	526	-1916	-899	1128
7-2	Farm-yard Manure	4171	2649	3645	-526	+ 996	3298
4o	Mixed Mineral Manure, alone... ..	2535	1920	491	-2104	-1429	1380
4a	Mix. Min. Man. and 200 lbs Amm. Salts=48 lbs N	4530	3120	2333	-2197	-787	3019
4aa	" " " and 275 lbs Nit. Soda=43 lbs N ...	5487	4057	2398	-3089	-1059	3343
4c	" " " and 1000 lbs Rape Cake=49 lbs N	4712	3705	2658	-2124	-1117	3065
TOTAL PRODUCE (Grain and Straw) per acre, LBS							
1o	Unmanured	4405	2878	943	-3462	-1935	2136
7-2	Farm-yard Manure	7296	5564	5724	-1574	+ 160	6140
4o	Mixed Mineral Manure, alone... ..	4969	4111	579	-4090	-3232	2739
4a	Mix. Min. Man. and 200 lbs Amm. Salts=48 lbs N	7958	6336	3867	-4091	-2469	5574
4aa	" " " and 275 lbs Nit. Soda=43 lbs N ...	9026	7734	3819	-5207	-3915	6042
4c	" " " and 1000 lbs Rape Cake=49 lbs N	6125	7241	4246	-3879	-2995	5667

NOTE.—Plot 4aa, Ammonium-Salts=86 lbs Nitrogen first 6 years, =43 lbs next 10 years; Nitrate Soda=43 lbs Nitrogen last 16 years. Plot 4c, 2000 lbs Rape Cake first 6 years; 1000 lbs. since.

For comparison with the produce of these selected years, the average on each of the six plots over the 32 years is given; and it will be seen how very much higher than the average is the produce in the good years, and how very much lower in the bad season.

So much for the variations in the amounts of produce in the different seasons. It will be of interest to consider, however summarily

it may be practicable to do it, some of the climatic characteristics of these various seasons.

The next Table (VI.) shows, for each month of each of the three seasons, reckoning from October to September, the mean temperature, and the rainfall, above or below the average.

Table VI

Characters of the two Best Seasons, 1854 and 1857, and of the Worst Season, 1879
Temperature and Rainfall + or — Average

	Mean Temperature			Rainfall			Days of Rain, 0·01 inch, or more		
	Best two		Worst	Best two		Worst	Best two		Worst
	1854	1857	1879	1854	1857	1879	1854	1857	1879
	Deg. F	Deg. F	Deg. F	Inches	Inches	Inches	Days	Days	Days
October	+1·3	+2·1	+1·9	+1·43	-0·69	-1·14	+13	-4	-1
November	-0·2	-1·6	-2·6	-0·45	-1·15	+1·05	-2	-8	+2
December	-5·2	+1·0	-5·5	-1·30	-0·27	-0·94	0	+1	+4
January	+2·4	0·0	-4·7	-0·60	+0·60	+0·59	+3	+7	0
February	+0·8	+0·5	-0·5	-0·29	-1·30	+2·32	-3	-8	+10
March	+2·7	+0·7	+0·1	-1·28	-0·77	-1·00	-6	-2	+2
April	+2·3	-0·4	-2·9	-1·11	-0·30	+0·90	-4	+7	+5
May	-1·6	+1·5	-4·1	+1·51	-1·67	+1·38	+5	-6	+4
June	-2·3	+3·8	-1·3	-0·99	+0·80	+2·39	+1	-2	+9
July	-1·3	+2·9	-3·5	-0·85	-1·50	+1·12	+4	-2	+8
August	0·0	+4·9	-1·0	+0·21	+0·10	+2·79	+1	0	+9
September	+1·6	+3·2	-0·2	-1·42	+1·00	+0·47	-3	+1	+2
Averages		+1·5	-2·0						
Totals				-5·14	-5·35	+9·91	+9	-11	+54

It is obvious that different seasons will differ almost infinitely at each succeeding period of their advance, and that, with each variation, the character of development of the plant will also vary, tending to luxuriance, or to maturation, that is, to quantity, or to quality, as the case may be. Hence, only a very detailed consideration of climatic statistics, taken together with careful periodic observations in the field, can afford a really clear perception of the connection between the ever-fluctuating characters of season, and the equally fluctuating characters of growth and produce. It is, in fact, the distribution of the various elements making up the season, their mutual adaptations, and their adaptation to the stage of growth of the plant, which, throughout, influence the tendency to produce quantity or quality. Still, it will be seen that the limited summary of the meteorological conditions of the seasons in question, which can alone be given here, is not without significance.

First then as to 1854, the season of great luxuriance and high total produce. The Table shows that there was an excess of temperature in January, February, March, and April, with a deficiency of rain from November to April inclusive; but that during May, June, and July,

that is the months of active above-ground growth, there were lower than the average temperatures, with a considerable excess of rain in May, and then a deficiency—conditions obviously favouring continued vegetation and slow maturation.

In 1857, there was less excess of temperature, and less than the average amount of rain to the end of April; then from May to August inclusive there was both considerable deficiency of rain and considerable excess of temperature; that is, there were throughout the period of active above-ground growth conditions favouring seeding tendency and maturation rather than luxuriance.

Thus, then, the two good seasons were very different in their climatic characteristics, as they were in the character of their produce.

Compared with these, the very bad season of 1879 shows much lower than average temperatures throughout the winter, spring, and summer, and even somewhat in the autumn, with, at the same time, great excess of rain from January to September inclusive; and it will be seen that both the deficiency of temperature and the excess of rain were very marked from April to August inclusive, that is, during the whole period of the above-ground growth, and the ripening, if such it may be called, of the crop, for in many cases the weight per bushel was less than 50 lbs., whilst the amounts of produce were, as has been seen, very greatly below the average.

Even then this very incomplete record of the climatic characters of the three seasons is sufficient clearly to indicate the connection between such conditions, and the characteristic differences in the three crops.

Influence of Exhaustion, Manures, and variations of Season, on the Composition of the Barley Crop.

I have now considered the influence of exhaustion, manures, and variations of season, on the *amount of produce* of Barley, and I propose briefly to consider their influence on its *composition*. When discussing last year the influence of various conditions on the composition of Wheat, it was shown that although the supplies within the soil—both of nitrogen and of mineral constituents—had a very direct influence on the composition of the crop so long as it was only in the vegetative stage, yet there was nevertheless very great uniformity in the composition of the final product of the plant—the seed—provided only that it was perfectly matured. The composition of the straw, however, showed a very direct connection with the supplies by the soil. The composition of the grain, on the other hand, was materially influenced by variations of *season*. But variations of season obviously have great influence on the condition of maturation; whilst difference in maturation implies difference in organic composition—in the amount of carbohydrates (starch especially)—formed. In fact, such variations in composition imply deviations from perfect and normal maturation; and such deviations are associated not only with differences in the organic composition—the relation of the nitrogenous to the non-nitrogenous constituents—but with differences in the mineral composition also.

It follows, from what has been said, that variations in the

composition of the final and very definite product—the seed, should be much more clearly traceable to variations of season than to the variations in the supplies within the soil; in other words, than to exhaustion or manures. This was found to be very strikingly so in the case of *wheat*, and we have now to consider how far it is so with its near ally—*barley*.

The results given in Table VII. forcibly illustrate the much greater influence of variations of season than of manures, on the composition of barley grain. Complete analyses of the ash of the grain (and also of the straw) grown by different manures, each in different seasons, have been made, and taking for illustration the important and characteristic constituents, potash and phosphoric acid, the Table shows for three very different manurial conditions—

1. Without manure,
2. With farmyard manure,
3. With an artificial manure supplying liberally both nitrogen and mineral constituents—

the highest, the lowest, and the mean amounts of potash and phosphoric acid, in 1000 parts of the dry substance of the grain, and of the straw, in the different seasons.

TABLE VII.

Highest, lowest, and mean amounts of potash and phosphoric acid per 1000 dry substance.

		Per 1000 Dry Grain					Per 1000 Dry Straw				
		Highest	Lowest		Mean		Highest	Lowest		Mean	
POTASH.											
1 O	Unmanured ...	1871	7.66	1853	6.00	6.54	1871	11.77	1856	5.25	8.55
7 2	Farm-yard Manure....	1871	8.36	1856	5.89	6.81	1871	22.01	1856	6.76	13.23
4 A	Mix. Min. Man. and Amm. Salts.	1871	7.98	1852	5.62	6.61	1871	22.53	1852	5.67	14.05
PHOSPHORIC ACID.											
1 O	Unmanured ...	1852	10.08	1854	8.85	9.27	1856	2.60	1863	1.20	1.74
7 2	Farm-yard Manure	1871	10.50	1854	9.23	9.99	1856	2.92	1863	1.48	2.19
4 A	Mix. Min. Man. and Amm. Salts....	1856	10.39	1863	8.84	9.58	1856	3.12	1863	1.06	1.94

First as to the amounts of potash in 1000 parts dry substance of grain of the differently manured plots in the different seasons. It is seen that there is much greater variation in the proportion of potash in different seasons with the same manure, than there is with different manures. Further, the seasons showing the highest amount of potash are those of much higher maturing character than those with the lowest amounts.

Next it is seen that there is still greater, indeed enormous variation, in the amount of potash in the dry substance of the straw with the

same manure, in different seasons. There is also great variation according to manure; comparatively little when there was full supply, but considerable without manure, that is with exhaustion.

Turning now to the phosphoric acid in the grain: there is here again much more variation in different seasons with the same manure, than with different manures. But whilst in the case of potash there is the higher proportion in the *better* seasons, in that of phosphoric acid there are lower amounts in the dry substance in the *better* seasons. In fact high amount of potash in the ash, and in the dry substance of the grain, is as a rule associated with high maturation, that is with high proportion of starch, whilst high proportion of phosphoric acid is generally associated with low maturation and high proportion of nitrogen.

The proportion of phosphoric acid in the straw, also varies more with season than with manure, and it is the highest in the worst seasons.

The connection between maturation and composition is further illustrated in the results given in Table VIII.

TABLE VIII.

General character of the produce, mean percentage in pure ash, and parts per 1000 dry matter, of Potash and Phosphoric Acid. Mean of 6 differently-manured plots in each season. Harvests in order of highest weight per bushel.

Harvests	Weight per bushel of Grain lbs.	Per cent. Ash (pure) in dry matter	Per cent. in Ash (pure)		Per 1000 dry matter.	
			Potash	Phosphoric Acid	Potash	Phosphoric Acid
GRAIN						
1871	55.9	2.65	29.80	35.33	7.89	9.39
1863	55.3	2.55	26.59	35.80	6.78	9.15
1852	51.7	2.48	23.84	40.89	5.90	10.18
1856	47.4	2.44	24.21	41.35	5.89	10.09
STRAW						
1871	55.9	6.27	26.01	3.68	16.57	2.31
1863	55.3	5.48	24.91	2.29	13.99	1.26
1852	51.7	4.45	14.62	4.05	6.58	1.81
1856	47.4	4.49	13.51	6.42	6.10	2.89

In the Table are given the mean results for six differently manured plots, in each of four very different seasons, so far as the maturation of the grain was concerned. The different seasons are given in the order of the highest weight per bushel of the grain—high weight per bushel being upon the whole the best practical measure of high quality.

It will be seen that, as so measured, the seasons are given in the following order—1871, 1863, 1852, and 1856,—the average weight per bushel of the grain being in 1871, 55.9 lbs.; in 1863, 55.3 lbs.; in 1852, 51.7 lbs.; and in 1856 only 47.4 lbs.; or about 8 lbs. less than

in the two seasons of highest weight. There is here, then, very great variation in the character of these four seasons, and in the degree of maturation of the grain accordingly.

The particulars of composition given for each of these four seasons are—the percentage of total mineral matter, or ash, in the dry matter of the grain, and of the straw; the percentage in the ash (of both grain and straw), of potash and phosphoric acid; and the amount of potash and phosphoric acid, in 1000 dry substance of both grain and straw.

No determinations of nitrogen are available, but it may be stated that the percentage of nitrogen is almost uniformly lower in the seasons of high maturation.

The Table shows that, in both grain and straw, there is a higher percentage of ash in the dry substance, the higher the quality of the grain. There are also higher percentages of potash, but lower percentages of phosphoric acid, in both the ash and the dry substance, the higher the quality of the grain.

In wheat, however, there is lower, not higher, percentage of ash in the dry substance of the grain, the higher its quality. But, in wheat, as in barley, there is higher percentage of potash, and lower percentage of phosphoric acid, in the ash, the higher the quality. On the other hand, there is not in the case of wheat, as there is in barley, a much higher percentage of potash in the dry substance, the higher the quality. This difference may be partly due to the larger proportion of starch to nitrogenous substance in the barley; but it is probably in part also due to the paleæ (or chaff) of the barley, but not of the wheat, being adherent, and retaining the surplus potash brought up for grain formation.

In both descriptions of grain there is very uniformly a lower proportion of phosphoric acid in the dry matter, the higher the quality of the grain.

In the straw, there is high percentage of ash in the dry matter, high percentage of potash, and low percentage of phosphoric acid, in the ash, and high percentage of potash, and low of phosphoric acid, in the dry matter, the higher the quality of the grain. In the straw, however, the variations show a much wider range, indicating much less definiteness, and greater irregularity in condition.

Thus, then, the higher the quality of the barley grain, that is the higher its proportion of starch, the higher is the proportion of potash, and the lower is that of phosphoric acid. It may be mentioned that with a higher proportion of potash there is generally a lower proportion of both lime and magnesia, and with a lower proportion of phosphoric acid there is a somewhat higher proportion of sulphuric acid.

Another point of interest is, although it is true the amounts are small, that there is a tendency to a higher proportion of soda in the grain ash, and in the dry matter of the grain, in the better seasons, even when there is no deficiency of potash. This, again, is probably due to the ash of the barley grain containing that of the adherent paleæ.

In relation to the composition of the straw, the most striking result is (though not shown in the Table) that there is little more than two thirds as high a percentage of silica in the ash of the produce of the better as in that of the worse seasons.

Thus far the effects of season, and coincidently with this the degree of maturity of the grain, on its composition, have chiefly been illustrated. The next results illustrate more directly the influence of *exhaustion*, or of *full supply*, of mineral, or ash constituents, on the mineral composition of the produce, both grain and straw.

The first three columns of Table IX. (p. 22), relate to the mineral composition of the produce grown for 25 years in succession, by ammonium salts and superphosphate of lime, but without supply of potash, soda, or magnesia. The last three columns show the composition of the produce by ammonium salts, and superphosphate, with potash, soda, and magnesia, in addition. There are given the results obtained by the analysis of proportionally mixed samples of the produce, of ten years 1852-61, of ten years 1862-71, and of five years 1872-76. The upper division of the Table gives for the potash, the second for the soda, the third for the phosphoric acid, and the fourth for the silica—1, the percentage in the ash (pure) of the grain and of the straw; 2, the amounts per 1000 dry matter of grain and of straw; 3, the amounts per acre per annum in lbs. in the total produce (grain and straw together), in the grain alone, and in the straw alone.

First referring to the potash, its percentage, even in the grain ash, is seen somewhat to diminish from period to period where none was supplied in manure; and in a somewhat greater degree to increase where there was an annual supply of it by manure. In the straw ash, however, whilst the percentage of potash goes down from 18·44 over the first period to only 8·70, or less than half, over the third period, where none was supplied, it increases from 27·85 per cent. over the first, to 34·43 per cent. over the third period, when it was annually supplied. Thus, the influence of exhaustion, or of full supply, has been comparatively small on the mineral composition of the grain, but very great indeed on that of the straw.

The point is further illustrated in the next results, showing the amounts of potash, per 1000 dry matter of grain, and of straw, respectively. There is again comparatively little variation in the relation of the potash to the organic matter in the case of the grain, but very great variation in the case of the straw; and when it is borne in mind, that the ash of barley grain contains that of the adherent paleæ as well as that of the grain proper, the conclusion is that the variation in the proportion of potash to the fixed organic substance of the grain itself is much less than the figures would indicate. Indeed, it is probable that the variation, such as it is, is associated with a different relative proportion of the organic compounds themselves—of the fully matured non-nitrogenous to the nitrogenous bodies. In fact, the evidence, duly considered, is not in favour of the view that there is variation in the proportion of the potash to the fixed and ripened

non-nitrogenous constituents, with the formation of which it is associated.

Table IX

Experiments on Barley, Hoosfield, Rothamsted. Potash, Soda, Phosphoric acid, and Silica, per cent in Ash, per 1000 Dry substance, and Quantities per acre

		Ammonium salts and Superphosphate			Ammonium salts superphosphate and potash, soda, and magnesia.		
		10 years 1852- 1861	10 years 1862- 1871	5 years 1872- 1876	10 years 1852- 1861	10 years 1862- 1871	5 years 1872- 1876
POTASH							
Per cent in Ash	{ of Grain.....	26.79	25.97	25.37	27.62	28.46	29.19
	{ of Straw.....	18.44	13.31	8.70	27.85	32.92	34.43
Per 1000 Dry Matter	{ of Grain.....	6.22	6.23	5.88	6.52	6.82	7.11
	{ of Straw.....	8.54	6.41	3.63	14.65	18.51	17.68
Per acre per annum. lbs	{ in Total Produce	35.60	30.88	18.16	53.74	63.73	53.05
	{ in Grain.....	13.07	14.45	11.33	13.80	15.23	13.87
	{ in Straw.....	22.53	16.43	6.83	39.94	48.45	39.18
SODA							
Per cent in Ash	{ of Grain.....	1.15	2.07	2.72	0.51	0.58	0.66
	{ of Straw.....	6.42	11.39	13.53	2.50	2.30	2.60
Per 1000 Dry Matter	{ of Grain.....	0.27	0.50	0.63	0.12	0.14	0.16
	{ of Straw.....	2.97	5.49	5.65	1.32	1.29	1.35
Per acre per annum. lbs	{ in Total Produce	8.40	15.21	11.85	3.84	3.69	3.27
	{ in Grain.....	0.56	1.15	1.22	0.25	0.31	0.31
	{ in Straw.....	7.84	14.06	10.63	3.59	3.38	2.96
PHOSPHORIC ACID							
Per cent in Ash	{ of Grain.....	38.55	36.36	38.20	38.53	37.31	38.61
	{ of Straw.....	3.06	2.55	3.48	2.97	2.47	3.15
Per 1000 Dry Matter	{ of Grain.....	8.95	8.72	8.85	9.10	8.95	9.39
	{ of Straw.....	1.42	1.23	1.45	1.56	1.39	1.63
Per acre per annum, lbs	{ in Total Produce	22.54	23.38	19.78	23.51	23.67	21.91
	{ in Grain.....	18.80	20.23	17.05	19.25	20.04	18.33
	{ in Straw.....	3.74	3.15	2.73	4.26	3.63	3.58
SILICA							
Per cent in Ash	{ of Grain.....	18.60	20.62	18.64	18.67	19.18	17.14
	{ of Straw.....	47.87	43.39	44.07	43.67	35.41	32.02
Per 1000 Dry Matter	{ of Grain.....	4.32	4.95	4.32	4.41	4.60	4.17
	{ of Straw.....	22.16	20.92	18.37	22.96	19.91	16.63
Per acre per annum, lbs	{ in Total Produce	67.55	65.05	42.92	71.96	62.42	44.58
	{ in Grain.....	9.07	11.47	8.32	9.33	10.30	8.14
	{ in Straw.....	58.48	53.58	34.60	62.63	52.12	36.44

The effects of exhaustion, or of full supply of constituents, is more strikingly still brought out by a study of the figures showing the amounts of potash taken up per acre by the crops without, and with, the supply of it. Thus, the average amounts of potash taken up, or rather retained, per acre per annum, in the entire crop (grain and straw together) are, over the three successive periods, without supply of it—35·60, 30·88, and 18·16 lbs. ; and with full supply they are, over the same periods—53·74, 63·73, and 53·05 lbs. That is to say there is without supply little more than half as much potash annually stored up in the crop over the last five years, as over the first ten years, of the 25. On the other hand, with full supply, there is, over the second period more than, and over the third period about the same amount as, over the first period ; and there is, over the first period about one-and-a-half time, over the second period twice, and over the third period nearly three times, as much as where there was no supply.

Yet, with these enormous differences in the amounts taken up and retained by the entire plant in the different cases, there is comparatively little difference in the amounts accumulated in the grain. Thus, over the first period, the amounts in the grain are—without supply 13·07 lbs., and with supply 13·80 lbs. ; over the second period—without supply 14·45 lbs., and with supply 15·28 lbs. ; and over the third period—without supply 11·33 lbs., and with supply 13·87 lbs.

It is thus seen that, over each period, there was rather less in the grain without than with supply, but that the deficiency was not material until the third period ; that is until after 20 years without supply in the one case, and 20 years with it in the other.

In reference to these results, it has already been shown, in discussing those in Table IV. (p. 12) that over a period of 32 years, that is extending seven years later than the 25 years to which the foregoing figures relate, there was almost identically the same amount of produce of grain, without as with the supply of potash ; though there was, on the other hand, rather more straw, especially in the later years, with the supply. It would appear, therefore, that the diminished amount of potash taken up by the plant was sufficient for the exigencies of grain-formation almost to the end of the period ; and that at least a large proportion of the excess taken up when it was liberally supplied was surplusage so far as the requirements of the grain were concerned. Some idea of how great was this surplusage may be formed by reference to the difference in the amounts of potash eventually remaining in the straw. Thus, the average amounts of potash per acre per annum in the straw were—over the first period, without supply, 22·53 lbs., and with supply 39·94 lbs., or 17·41 lbs. more ; over the second period, without supply 16·43 lbs., and with supply 48·45 lbs., or 32·02 lbs. more ; and over the third period, without supply 6·83 lbs., and with supply 39·18 lbs., or 32·35 lbs. more. It is not to be supposed, however, that the whole of these plus-amounts were surplusage ; for although the average yield of grain has been so well maintained, the character of the plant has obviously depreciated for a good many years,

and several times in recent years even the yield of grain has been considerably deficient. Indeed, it would seem that the plant has become more sensitive to adverse conditions of soil or season.

Turning now to the soda, it is seen that whether we look at its percentage in the ash of the grain, and of the straw, its proportion in 1000 dry substance, or the amounts in the acreage crops, very much more was found in the crops grown without its supply, but where potash was deficient, than where soda was annually supplied. This is strikingly illustrated by reference to the average amounts per acre per annum in the total crops, grain and straw together. Thus, over the first period, the average amounts of soda in the total crop were, without any supply of either potash, soda, or magnesia, 8.40 lbs., and with the supply of all three, only 3.84 lbs.; over the second period, without the supply 15.21 lbs., and with the supply only 3.69 lbs.; and, lastly, over the third period, without the supply 11.85 lbs., and with the supply only 3.27 lbs.

Thus, then, not only was there much more soda taken up, or retained, by the plant where it was not supplied than where it was, but it is evident that there was the more soda taken up the less the supply of potash. The amounts of soda retained in the grain are, however, seen to be but small; there is more it is true where there was a deficiency of potash, and where more soda was taken up. But, looking to the amounts of soda per cent. in the grain ash, or per 1000 dry substance of the grain, it would seem probable that the larger amounts where there was deficiency of potash, and more total soda taken up, were probably only due to larger amounts eliminated from the grain proper, and retained in the adherent paleæ, or chaff. Whether, however, the soda has been of any avail, in the earlier, or merely vegetative stages of growth, as a carrier, or otherwise, may be a question.

Next as to the phosphoric acid, of which there was the same annual supply on both plots. It is seen that whether we take its percentage in the ash, its proportion to the dry substance, or its average quantity per acre, the amounts are, in the comparable cases, comparatively uniform; the differences not being greater than can be supposed to be connected with the differences in growth due to the differences in the supply of other constituents.

Lastly, as to the silica: the chief point of interest to remark is, that, as the figures show, its percentage in these barley grain ashes ranges from 17 to more than 20, whereas in wheat grain ash it ranges only from about 0.5 to about 1.5 per cent.; or, if we take the proportion of silica to 1000 dry substance of grain, in barley it ranges from 4 to 5 parts, and in wheat only from about 0.1 to about 0.3 parts. This difference is obviously due to the chaff being adherent in the case of barley, and not in that of wheat; and the figures afford clear illustration of the material degree in which the composition of barley grain-ash is influenced by the inclusion in it of what is, in a sense, extraneous matter. It is indeed obvious that, under such circumstances, we should

expect, as we find, less definiteness in the mineral composition of the grain of barley than in that of wheat.

On what does Strength of Straw depend?

It will be appropriate to refer here to the bearing of experimental evidence on the question whether, as is frequently stated, strength of straw is dependent on a high percentage of silica. Table X. (p. 26) affords illustrations on this point. The upper division of the Table gives results relating to wheat, and the lower division corresponding results relating to barley. In the case of wheat five, and in that of barley three, very different conditions of manuring are selected for illustration; and for each condition as to manuring results obtained in bad and in good seasons, are given. The particulars indicating the character of the crops are—the percentage of grain in the total produce, and the weight per bushel of the dressed grain; and side by side with these are recorded—the percentage of ash in the dry matter of the straw, the percentage of silica in the ash, and the percentage of silica in the dry matter.

In the wheat in every case, and in the barley in every case but one, there is a higher proportion of grain in the better season; and in every case, of both wheat and barley, there is a much higher weight per bushel of grain in the better season. These conditions are, in fact, proof of the superiority of the crops in the main characters of seed-forming tendency, and ripening.

The percentage of ash in the dry matter of the straw is not a very significant character; and it is seen that in the case of the wheat it was on the average somewhat the lower, but in that of the barley uniformly the higher in the better seasons.

The percentage of silica in the straw ash is more significant, and in both the wheat and the barley it is under all the conditions of manuring much the lower in the better seasons. More significant still, is the percentage of silica in the dry matter of the straw, and it is seen that, with the wheat under each condition of manuring, and with the barley under most conditions, it is considerably lower in the better seasons. It may be observed that the exceptions in the case of the barley were where organic manure, as in rape-cake and farm-yard manure, was employed.

Direct analytical results clearly show, therefore, that the proportion of silica is, as a rule, lower, not higher, in the straw of the better grown and better ripened crops.

This result is quite inconsistent with the usually accepted view that high quality and stiffness of straw depend on a high amount of silica. Pierre and Bretschneider have, however, concluded from their experiments that this is not the case, and at Rothamsted we have long maintained a contrary view. In fact, high proportion of silica means a relatively low proportion of organic substance produced. Nor can there be any doubt that strength of straw depends on the favourable development of the woody substance; and the more this is attained the more will the accumulated silica be, so to speak, diluted—in other words, show a lower proportion to the organic substance.

TABLE X.

Per cent. Silica in the Ash, and in the dry matter, of Wheat Straw and Barley Straw grown by different manures, and in different seasons.

		Per cent. Corn in Total Produce	Weight per bushel dressed corn	Per cent. Ash in dry matter	Per cent. Silica in Ash	Per cent. Silica in dry matter
WHEAT						
Without Manure	1856	36.4	54.3	5.5	71.47	2.38
	1858	40.6	60.4	4.9	65.85	3.23
Amm. Salts alone	1856	34.8	55.5	3.9	66.23	2.58
	1858	40.3	59.6	4.0	57.47	2.30
Mixed Mineral Manure	1856	36.7	56.4	5.7	68.74	3.22
	1858	43.6	61.5	5.6	64.07	3.62
Mineral Manure and Amm. Salts	1856	38.6	58.0	4.9	64.63	3.17
	1858	38.2	63.2	5.0	55.60	2.78
Farm-yard Manure	1856	34.5	58.6	6.7	69.56	4.66
	1858	39.6	62.6	6.54	59.71	3.90
BARLEY						
Rape cake	1853	44.3	51.7	4.75	57.49	2.73
	1871	45.4	56.3	5.54	42.04	2.33
Rape cake	1856	39.1	46.1	4.63	49.39	2.29
	1863	48.4	56.3	5.17	45.62	2.36
Mineral Manure and Amm. Salts	1853	43.3	51.4	4.19	63.21	2.61
	1871	43.3	56.5	6.70	32.71	2.19
Mineral Manure and Amm. Salts	1856	40.2	46.4	5.48	57.47	3.15
	1863	47.3	56.5	6.32	35.24	2.23
Farm-yard Manure	1853	47.0	52.3	5.15	57.38	2.96
	1871	43.8	56.6	7.55	42.71	3.22
Farm-yard Manure	1856	42.3	47.1	4.92	57.85	2.85
	1863	48.3	57.2	6.21	43.08	2.68

I may mention that in my own neighbourhood, where the straw-plait industry prevails, the complaint during several recent seasons of bad harvests was that an unusually large proportion of the straw was brittle, and broke in the working; and considering the character of the seasons there can be no doubt that this was associated with low development of the woody matter, and high proportion of silica.

Our Area under the Crop, and the Amount of our Imports.

Before concluding on the subject of barley, it will be of interest to consider the extent of area devoted to the crop in the United Kingdom, the amount of our total annual imports, and from what countries our supplies are chiefly derived.

Table XI. (p. 27) shows the area under the crop in the United Kingdom, in each of the last 13 years, 1873 to 1885 inclusive. It also shows the total imports into the United Kingdom during the year

succeeding each of the first 12 of the 13 harvests, reckoning from September 1 to August 31 in each case.

The figures show that since the harvest-year 1880-81, there has been a reduction of area. Further, the last column shows that since the same date there has been a considerable increase in our imports.

TABLE XI.

Area under Barley in the United Kingdom; also Imports into the United Kingdom, during each harvest year from 1873-4 to 1885-6.

Harvest Years	Area	Imports
	Acres	Quarters
1873-4	2,574,529	2,381,785
1874-5	2,507,130	2,667,174
1875-6	2,751,362	2,272,081
1876-7	2,762,263	2,684,725
1877-8	2,652,300	2,976,384
1878-9	2,723,979	2,798,494
1879-80	2,931,809	3,467,147
1880-1	2,695,000	2,974,892
1881-2	2,662,927	3,725,384
1882-3	2,452,077	4,398,127
1883-4	2,486,137	4,081,722
1884-5	2,346,041	4,726,908
1885-6	2,447,169	

NOTE.—The Area refers to the first of the two dates opposite to which it is placed; the Imports refer to the succeeding harvest year—September 1st to August 31st.

Now, it was in 1880 that the repeal of the malt-tax took place; a change which it was maintained by its advocates in the agricultural interest, would greatly encourage the home growth of barley. The actual result has been, however, a diminution of our own area, and an increase in our imports. It would seem that the high duty served as a bounty on the higher qualities of our own production, and that when this was removed, the greater demand for medium qualities has given an advantage to the foreign grower.

Nor has the removal of the duty led to an extended use of malt for feeding purposes, which was one of the main objects for which the repeal was strongly advocated by farmers. At Rothamsted, much careful experiment led us long ago to the conclusion that the advocacy of repeal on these grounds was illusory, and for our pains we have been accused of not being the farmers' friends! The result has, however, fully justified the view we took on the point.

Table XII. (p. 28) shows the imports of barley from different countries over the 16 civil years to 1884 inclusive. The countries are arranged in the order of their highest average supply over those years. It will be seen that both in average, and in detail in recent years, Russia is the most important source. France and Germany show fairly equal average amounts, but Germany has sent us decidedly the most in recent years. On the other hand, it is remarkable how very large was the amount sent us by France in 1872; that is just after the war.

TABLE XII.
Imports of Barley from different Countries, into the United Kingdom, 16 years—1869-1884.

Years	Russia	France	Germany	Turkey	Roumania	Denmark	Sweden	United States	Egypt	Chili	Other Countries	Total	Years
1869	Quarters 277,108	Quarters 431,020	Quarters 405,249	Quarters 434,369	Quarters 79,561	Quarters 285,465	Quarters 53,548	Quarters 285	Quarters 21,976	Quarters 1,265	Quarters 323,417	Quarters 2,355,055	1869
1870	717,597	125,203	333,248	117,108	60,146	473,539	115,973	...	7,819	...	34,343	2,030,853	1870
1871	671,656	434,715	333,635	313,080	130,967	297,473	99,839	16,517	1,814	...	108,567	2,999,323	1871
1872	491,498	1,731,259	468,323	419,777	841,109	510,858	100,368	4,944	19,609	...	135,446	4,313,039	1872
1873	313,346	551,868	318,646	813,581	234,260	238,003	50,961	4,068	4,693	3	87,949	2,667,498	1873
1874	665,421	594,196	303,919	931,568	368,485	373,337	95,613	9,016	13,516	1,865	113,001	3,173,913	1874
1875	723,956	532,891	313,394	714,966	133,133	333,597	131,275	3,168	35,746	63,798	64,945	3,093,663	1875
1876	433,305	459,780	130,776	905,983	370,061	378,325	89,737	36,000	76,361	196	65,901	2,798,435	1876
1877	419,878	532,015	735,904	1,059,773	59,448	378,605	89,111	326,073	...	1,947	176,006	3,636,667	1877
1878	1,351,746	123,679	832,005	237,523	339,233	519,149	128,964	303,677	...	...	63,971	3,963,537	1878
1879	692,469	175,190	1,008,144	35,004	439,516	594,371	137,488	44,366	92,406	16,899	83,095	3,333,968	1879
1880	417,610	326,949	738,317	33,391	676,951	593,168	130,433	91,597	35,071	66,761	174,533	3,977,481	1880
1881	327,018	550,331	473,646	70,560	628,398	385,534	64,156	76,631	16,792	951	941,468	2,745,665	1881
1882	1,147,256	254,713	609,150	143,736	1,601,596	297,616	155,872	13,323	13,571	1,918	113,468	4,351,321	1882
1883	1,544,774	413,200	502,576	331,354	1,348,968	210,010	111,301	33,953	26,835	14,801	173,173	4,609,174	1883
1884	1,390,365	365,753	302,869	673,017	392,339	63,535	49,305	63,465	63,035	61,697	936,413	3,626,844	1884
Mean	717,538	450,879	477,951	453,333	430,904	368,847	100,259	57,933	26,501	16,274	133,917	3,244,746	Mean

In the above Table, the Imports are given for the Civil years, not the Harvest years.

Turkey contributes very variable quantities ; as also does Roumania, which gives an average of nearly one and a half million quarters in 1882 and 1883, and little more than one-third of a million in 1884. Denmark supplies more than Sweden ; but upon the whole somewhat diminishing amounts in recent years. The United States send comparatively small, and upon the whole diminishing quantities in recent years ; whilst Egypt and Chili send on the average less still, but considerably increased quantities in the last year for which the records are given—1884.

Conclusion.

I have now illustrated the influence of exhaustion, of manures, and of variations of season, on the amounts of produce, and on the composition, of barley.

It has been seen that its requirements within the soil, and its susceptibility to the external influences of season, are very similar to those of its near ally, wheat ; but that there are distinctions of result, dependent on differences in the habits of the plants, and in the conditions of their cultivation accordingly.

Wheat is as a rule sown in the autumn, in a heavier and closer soil, and has four or five months in which to distribute its roots and get possession of a wide range of soil and subsoil before barley is sown.

Barley is sown in a lighter surface soil, and, with its short period for root development, relies in a much greater degree on the stores within the *surface soil*. Accordingly, it is more susceptible to exhaustion of surface soil as to its nitrogenous, and especially as to its mineral supplies ; and in the common practice of agriculture it is found to be more benefited by direct mineral manures, especially phosphatic manures, than is wheat when sown under equal soil conditions.

The exhaustion induced by both crops is, however, characteristically that of available nitrogen ; and when, under the ordinary conditions of manuring and cropping, artificial manuring is still required, nitrogenous manures are as a rule requisite for both crops, and for the spring-sown one, barley, superphosphate also.

It has been seen, that under the influence of foreign competition (and possibly in part due to the greater attention paid to meat and milk production in later years), the area under the crop has been reduced. But there is no doubt that, in addition to the soils on which it is most appropriately grown in the ordinary course of rotation, barley may be grown, both in full quantity per acre, and of good quality, in succession to wheat, on the heavier soils, when the land is clean enough for a second corn crop.

RESULTS OF EXPERIMENTS AT ROTHAMSTED,
ON THE
GROWTH OF ROOT-CROPS

FOR MANY YEARS IN SUCCESSION
ON THE SAME LAND;

BEING

A LECTURE DELIVERED JULY 27, 1887,

AT THE

ROYAL AGRICULTURAL COLLEGE,
CIRENCESTER,

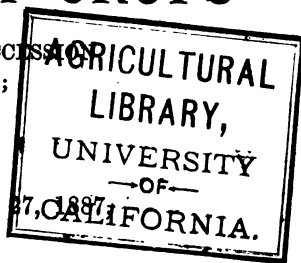
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RESULTS OF EXPERIMENTS AT ROTHAMSTED, ON THE GROWTH OF ROOT-CROPS, FOR MANY YEARS IN SUCCESSION ON THE SAME LAND.

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INTRODUCTION.

In my lecture here two years ago, I gave an account of the experiments at Rothamsted on the growth of wheat for more than forty years in succession on the same land, without manure, with farmyard manure, and with a great variety of artificial manures; and last year I gave an account of somewhat parallel experiments on the growth of barley, for more than thirty years in succession on the same land.

On the present occasion I propose to direct attention to the results of experiments on various root-crops, which have also been grown for many years in succession on the same land; in fact, with the exception of the three years, 1853, 1854, and 1855, from 1843 up to the present time; comprising, therefore, a period of 45 years, in 42 of which roots have been grown.

Hitherto, then, the conditions of growth, and the composition, especially so far as this is influenced by those conditions, of certain crops of the great gramineous family cultivated for their seeds, and which are therefore allowed to fully ripen, have been considered.

The remarkable fact was brought out, that these gramineous crops, which, when ripe, contain a low percentage of nitrogen in their dry substance, and accumulate a comparatively small amount of it over a given area, are nevertheless specially benefited by the application of nitrogenous manures; whilst leguminous crops, which not only contain a much higher percentage of nitrogen in their dry substance, and yield a much greater amount of it over a given area, are not specially benefited by nitrogenous manures. This was not supposed to indicate that they relied on the atmosphere for their nitrogen; but to be connected with a different character and range of roots, by virtue of which these

plants—the Leguminosæ—are enabled to avail themselves of soil-sources of nitrogen of which the Gramineæ are unable to take advantage.

The *Root-crops*, the conditions of growth, and the composition, of which we have now to consider, include members of more than one Natural Family of Plants; and they are grown, not for their seed, but for, so to speak, certain intermediate parts and products, which are, by cultivation, very abnormally developed; whilst the crops are not allowed to ripen, but are taken when in a succulent and immature condition. We shall thus have interesting points of comparison, or contrast, brought out, as to the conditions of growth of these crops, and of those to which we owe the cereal grains.

The crops to which I shall specially direct attention are some varieties of turnips, belonging to the order Cruciferae, and a variety of beet, namely, the feeding mangel, of the natural order Chenopodiaceæ.

The introduction of turnips into our agricultural rotations may be said to have been one of the most important improvements of recent times. The growth of the crop constitutes, indeed, an essential element, not only in the ordinary four-course rotation, but in all our varied rotations.

From certain characters of the turnip plant, especially its abundant leaf-surface, and from certain conditions of its growth, it has frequently been assumed that it is largely dependent on the atmosphere for its nitrogen; and that it is, in fact, thus a collector of nitrogen for the crops grown in alternation with it. But we shall see that experimental evidence does not support this conclusion; and that we must look in other directions for an explanation of the undoubted benefits of the growth of root-crops in rotation.

The object to be attained in the cultivation of root-crops is, it should be remembered, to encourage, by artificial means, a quite abnormal development of a particular part of the plant. If the turnip plant were grown for its natural seed-product, oil, a heavier soil would be more suitable than when the object is to develop the swollen root; in our climate a biennial habit would be induced, and it would be so grown as to be exposed to the summer temperature at a later stage of the development, or life history, of the plant—that is at the seed-forming and ripening period. Under these circumstances there would be much less of fibrous root distributed through the surface soil, the main root would be much less bulbous, and more fusiform, tapping rather than spreading laterally; the leaves and stem would be much larger, both actually and proportionally to the root, and the enlarged root itself would serve as a store of material for the second or final growth.

To obtain the cultivated root, however, as grown as a food and rotation crop, the conditions required are very different. The seed is sown at a different period, and the character of the manuring, and of the season of growth chosen, are, in their conjoint influence, such as to favour a very abnormal accumulation of the store material of the root, and to secure that this development shall attain a maximum within the limits of the season.

It is no objection to what has been said, that, in selecting plants from which to grow seed, for the future growth of the cultivated root, those having the most symmetrical roots are chosen, rather than such as are more tapping, and betray a more characteristic seed-forming tendency. In this case it is not the most abundant natural seed that is the object of culture, but a seed having a special habit of growth, which habit it is desired to propagate. Yet it will be seen how very soon the cultivated turnip will revert to its more natural characteristics, if the mode of culture be not such as to favour the artificial development.

It is well to state these general facts before entering upon any detailed illustrations, the bearings of which will be better understood, if the essentially artificial conditions of growth which are induced be clearly borne in mind.

The first results I shall adduce are those of experiments with a variety of the common turnip, or *Brassica rapa*—the *Norfolk White*.

EXPERIMENTS WITH NORFOLK WHITE TURNIPS.

Every one knows that root crops—whether common turnips, swedish turnips, or mangel wurzel—are, in ordinary practice, grown by the aid of large dressings of farmyard manure; with, or without, artificial manures in addition; the farmyard manure being, in some cases, applied for the preceding grain-crop, but more generally directly for the root-crop itself. It will be well, therefore, briefly to refer to the results obtained with Norfolk white turnips, by the use of farmyard manure, at the rate of 12 tons per acre per annum, for three years in succession; and, for comparison, those obtained in the same seasons without manure, are also given.

TABLE I.
Produce of Norfolk White Turnips, without Manure, and with
Farmyard Manure.

Seasons.	Roots.		LEAVES.	
	Without Manure.	With Farmyard Manure.	Without Manure.	With Farmyard Manure.
1843	Tons. Cwts. 4 3½	Tons. Cwts. 9 9½	} Not weighed.	Tons. Cwts. Not weighed.
1844	2 4½	10 15½		7 7½
1845	0 13½	17 0½		
Mean	2 7½	12 8½		

Thus, then, the produce of this assumed restorative crop, when grown without manure, goes down in the third year to 13½ cwts. per acre; whilst in the third year with farmyard manure there was more than 17 tons.

By the use of 12 tons of farmyard manure per acre per annum for three years in succession, an average produce of about 12½ tons of

roots was obtained. But the amount varied very much indeed according to season; it being nearly twice as great in the third year as in the first. Accumulation of manure in the soil would aid this result, as the season was very favourable for the growth of the crop; but the accumulation, without the favourable conditions of season, would not have sufficed.

It may be observed that the first season, 1843, was characterised by great vicissitudes of both rainfall and temperature; 1844 was both hot and dry at the commencement, with too little total rain till October; whilst the season of most luxuriant growth, 1845, had a sufficient amount, and considerable continuity of rain, and only moderate temperatures, throughout.

Now, farmyard manure, which has yielded these amounts of produce, contains more or less of every constituent required for the growth of the turnip; and of some very important manurial matters, the amount of manure applied would contain much more than did the crop yielded. This would be the case so far as the nitrogen, and most of the mineral constituents, are concerned. Of nitrogen, for example, the 12 tons of farmyard manure would probably contain from 160 to 170 lbs., whilst the average produce of $12\frac{1}{4}$ tons of roots would probably not contain one-third as much. It is true that the leaf, as we shall presently see, would also have accumulated in it a considerable quantity of nitrogen; but besides this a large proportion of that supplied in the manure would remain in the soil in a condition only slowly available to vegetation.

It is to these facts—the large amount of farmyard manure generally applied for the growth of root-crops, the large amount of the nitrogen, and other constituents, remaining in the leaf, which serve directly as manure again, and the large proportion of the constituents of the manure itself which remain and slowly become available to succeeding crops,—that the value of the root-crop in rotation is largely to be attributed.

But another very important factor is, that these crops are, so to speak, gross-feeders, or rapid converters of manure into vegetable produce, and when the edible portion—the root—is consumed by store or fattening stock, a very small proportion of the nitrogen, and other constituents valuable as manure, is retained by the animal. The remainder, perhaps more than 90 per cent. of the nitrogen, is voided by the animals, and becomes manure again. When, however, roots are consumed for the production of milk, a much larger proportion is lost to the manure.

To sum up: a large amount of the manure is converted into vegetable substance, but a still larger amount remains in the soil for future crops; the substance grown provides a large amount of food for animals, but the greater proportion of its constituents remains, or returns, as manure again. Lastly, in addition to these advantages, the opportunity which the growth of the crop affords for the cleaning of the land, constitutes another important element of value.

The next question to consider is—which constituent, or class of constituents, of the complex material, *farmyard manure*, has the most characteristic influence on the growth of the root crop?

Table II. gives some illustrations on this point. It shows the average yield, over four consecutive seasons, 1845-48, of roots, of leaves, and of total produce, of Norfolk white turnips, grown without manure, and with a variety of artificial manures. The upper division of the Table shows the produce without mineral manure, and the lower division shows in each case the mean produce of three different mineral manures, namely, 1—Superphosphate of lime (plot 5); 2—Superphosphate and potash salt (plot 6); 3—Superphosphate, and potash, soda and magnesia salts (plot 4).

TABLE II.

NORFOLK WHITE TURNIPS.

Grown year after year on the same land, Barnfield, Rothamsted.

Results showing the effects of exhaustion and manures, four seasons, 1845-'48.

Manures and produce per acre per annum.

	SERIES 1. No Nitrogenous Manure.	SERIES 3. Ammonium Salts = 45 lbs. Nitrogen.	SERIES 4. Ammonium Salts and Rape Cake = 135 lbs. Nitrogen.	SERIES 5. Rape Cake = 90 lbs. Nitrogen.
WITHOUT MINERAL MANURE. (Three years only, 1846-'48).				
	Tons. Cwts.	Tons. Cwts.	Tons. Cwts.	Tons. Cwts.
Roots	1 4	1 7	5 10	6 11
Leaves	0 17	1 0	3 19	3 3
Total	2 1	2 7	9 9	9 14
WITH VARIOUS MINERAL MANURES.				
	8 4	9 18	10 5	11 0
Roots	2 14	4 6	6 3	4 12
Leaves				
Total	10 18	14 4	16 8	15 12

In the upper part of the first column are given the results without manure, and in the lower part of it those with the mineral manure alone; in the second column those with ammonium-salts, in addition, supplying 45 lbs. of nitrogen per acre per annum; in the third those with rape cake and ammonium-salts in addition = 135 lbs. nitrogen per acre; and in the fourth those with rape cake = 90 lbs. nitrogen per acre per annum in addition.

The first point to notice is—that on some of the manured plots there is an average of about 11 tons of roots, and more than $4\frac{1}{2}$ tons of leaves, giving a total produce per acre of more than $15\frac{1}{2}$ tons. *Without manure*, on the other hand, this assumed *restorative crop* yields

an average of only 1 ton 4 cwts. of roots, 17 cwts. of leaves, and a total produce of only 2 tons 1 cwt. The character of the unmanured root was, moreover, totally different. It had more the shape of a carrot than of a turnip; whilst its composition was also totally different from that of the cultivated root.

The difference, both in the amount of produce and in the composition of the cultivated as compared with the more natural root, is strikingly illustrated by the following figures, which relate to the crops of the third season of the experiments, 1845. Thus we have :—

	Roots per acre.		Nitrogen per cent. in Dry Matter.
	Tons.	Cwts.	Per cent.
Without Manure... ..	0	13½	3·31
Farmyard Manure	17	1	1·56
Superphosphate of Lime	11	2	1·52

That is to say, under the influence of manure there is a very large amount of non-nitrogenous substance accumulated, diluting, so to speak, the high percentage of nitrogen of the natural, uncultivated root. Not that more nitrogen is not also taken up by the cultivated plant, but in it there is, in proportion to the nitrogen, a large amount of other matters formed, the accumulation of which converts the plant into an important food-crop.

It will be seen that even mineral manures alone, and it is especially those which contain phosphates, have a very marked effect in inducing such accumulation; and it is pre-eminently by the action of such manures that a great amount of fibrous root is developed in the surface soil, under the influence of which more nitrogen, and at the same time more mineral matters, are taken up.

The results in the other columns of Table II. show, that the addition of nitrogenous manure, whether as ammonium-salts, or as rape-cake, or both, gives a further increase in the produce of the roots. But the second line of each division of the Table shows that a prominent effect of the nitrogenous manures is largely to increase the production of leaf. Thus, the average amount of leaf is increased from 2 tons 14 cwts. by mineral manure alone, to 4 tons 6 cwts. with ammonium-salts in addition, to 4 tons 12 cwts. with rape-cake in addition, and to 6 tons 3 cwts. with both ammonium-salts and rape-cake in addition.

The next Table, III., shows, first the average proportion of leaf to 1000 of root, under the four characteristically different conditions as to manuring. It also shows the percentages of dry matter in the roots and leaves respectively; and the percentages of nitrogen and of total mineral matter (ash) in the dry matter. In the lower division of the Table are given the amounts per acre of each of these constituents, in the roots and leaves respectively, and the amounts per acre more or less in the leaf than in the root.

TABLE III.

NORFOLK WHITE TURNIPS.

Grown year after year on the same land, Barnfield, Rothamsted.

Proportion of leaf to root, and selected constituents in root and leaf.

Per cent. and per acre.

Mean of plots 4, 5, and 6; four years, 1845-1848.

			SERIES 1.	SERIES 3.	SERIES 4.	SERIES 5.
			No Nitrogenous Manure.	Ammonium Salts = 45 lbs. Nitrogen.	Ammonium Salts and Rape Cake = 135 lbs. Nitrogen.	Rape Cake = 90 lbs. Nitrogen.
LEAF TO 1000 ROOT.						
			329	434	600	418
PER CENT.						
Dry Matter	In root		8.54	8.07	7.66	7.96
	In leaf		14.56	13.54	12.43	12.94
Nitrogen in Dry	In root		1.60	2.64	2.45	1.78
	In leaf		3.75	3.68	(3.68)	(3.68)
Mineral in Dry	In root		7.26	8.22	9.03	8.30
	In leaf		12.24	11.88	11.12	11.87
PER ACRE, lbs.						
Dry Matter	In root		1581	1807	1770	1963
	In leaf		853	1289	1703	1296
	Leaf + or - root		- 729	- 518	- 67	- 667
Nitrogen	In root		25	48	43	35
	In leaf		32	48	63	48
	Leaf + or - root		+ 7	0	+ 20	+ 13
Mineral Matter	In root		118	148	160	165
	In leaf		100	151	187	151
	Leaf + or - root		- 18	+ 3	+ 27	- 14

Thus, with the *Norfolk White Turnip*, we have from less than one-third as much leaf as root without nitrogenous manure, to nearly two-thirds as much with the largest supply of nitrogen by manure—that is with the greatest luxuriance of growth.

The economic importance of the difference in the proportion of leaf to root, not only under the influence of different conditions as to

manuring, but in different descriptions of root-crops, will be rendered obvious by the other results given in the same Table, and similar results given in corresponding Tables relating to *Swedish Turnips* and to *Mangel Wurzel*.

First as to *Norfolk White Turnips*:—not only is there the large proportion of leaf, but the leaf contains a very much higher percentage of dry matter than the root; and there is a very much higher percentage of both nitrogen and total mineral matter in the dry substance of the leaf.

The significance of these facts is more clearly brought out in the lower division of the Table, which shows the amounts per acre, in root and in leaf, respectively, of dry matter, of nitrogen, and of total mineral matter, under the different conditions of manuring; also the amounts of these in the leaf + or — the amounts in the roots.

It is seen that, owing to the much higher percentages of dry matter, and of nitrogen and mineral matter in the dry matter, of the leaf, the proportion of these in the leaf per acre, is much greater than is indicated by the proportion of the fresh leaf itself. We have, in fact, in one case, that with the highest nitrogenous manuring, nearly as much dry or solid matter per acre in the leaf, which for the most part only becomes manure again, as in the edible part of the crop, *the root*. In three cases there is actually more of the nitrogen of the crop in the leaf, remaining for manure, than there is in the portion available as food. There is also, in two cases, more of total mineral constituents in the leaf than in the root.

EXPERIMENTS WITH SWEDISH TURNIPS.

We will now turn to the consideration of similar particulars relating to other descriptions of Roots, and among these I will first direct attention to another very typical root-crop, namely the *Swedish Turnip*, *Brassica campestris rutabaga*.

The illustrations adduced are drawn from results obtained in the same field, on the same plots, and with, to a great extent, similar manures, as in the case of the *Norfolk White Turnip* already considered. The mineral manures were in fact practically the same throughout, and the nitrogenous manures were nearly the same in the first two of the four years, 1849 and 1850, but in the second two no nitrogenous manures were used. Further, the results were obtained in the next succeeding four years to those in which the *Norfolk Whites* were grown.

Table IV. shows the average amounts of produce—roots, leaves, and total—under the different conditions of manuring, over the four years, two with and two without nitrogenous manures; and Table V. shows the proportions of leaf to root, the percentage of dry matter, and the percentages of nitrogen and of mineral matter in the dry matter, in each; also the amounts of dry matter, nitrogen, and mineral matter per acre, in leaf and in root, respectively.

Compared with the produce of the *White Turnip*, that of the *Swedish Turnip* shows upon the whole rather less root without

nitrogenous manure, that is with the mineral manure alone, owing to the gradual exhaustion of the nitrogen of the soil where none had been applied by manure for a number of years. But on the other hand there is, with nitrogenous manures, in two cases out of three, more of the Swedish than of the White Turnip root.

TABLE IV.

SWEDISH TURNIPS.

Grown year after year on the same land, Barnfield, Rothamsted.

Results showing the effects of exhaustion and manures, four seasons, 1849-'52.

Manures and produce per acre per annum.

	SERIES 1. No Nitrogenous Manure.	SERIES 3. Ammonium Salts = 43 lbs. Nitrogen. ('49 & '50 only.)	SERIES 4. Ammonium Salts and Rape Cake = 141 lbs. Nitrogen. ('49 & '50 only.)	SERIES 5. Rape Cake = 98 lbs. Nitrogen. ('49 & '50 only.)
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WITHOUT MINERAL MANURE.

	Tons. Cwts.	Tons. Cwts.	Tons. Cwts.	Tons. Cwts.
Roots	2 6	3 17	7 0	7 14
Leaves (¹)	0 6	0 6	0 17	0 13
Total	2 12	4 3	7 17	8 7

WITH VARIOUS MINERAL MANURES (Plots 4, 5, and 6).

	7 5	8 18	12 2	11 9
Roots	7 5	8 18	12 2	11 9
Leaves (¹)	0 10	0 11	0 19	0 15
Total	7 15	9 9	13 1	12 4

(¹) Average of three years only, 1850-'52, leaves in 1849 not weighed.

A very important point to notice is, that there was, even when there was more root, very much less leaf in the case of the Swedish Turnip. Thus, whilst with the highest nitrogenous manure there was, with an average of $10\frac{1}{2}$ tons of the White Turnip roots nearly $6\frac{1}{2}$ tons of leaves, there was with the Swedish Turnip, with more than 12 tons of roots, not quite one ton of leaf. Here, then, the result of growth is that almost the whole of the accumulation is in the food-product, the root; and a very insignificant amount remains in the leaf, most of it simply to become manure again.

This point will be more clearly illustrated by the results given in Table V. But before turning to it, it may here be observed, though the fact is not shown in the merely mean results given in the Table, that there was very little influence from potash manures, excepting where, with the aid of liberal nitrogenous manuring, there was much increased luxuriance, and with this a greater drain on the stores of potash of the soil itself.

Let us now turn to the results in Table V., which gives the leaf to 1000 root, and the same particulars as before relating to the percentage composition of each, and to the amounts of the selected constituents *per acre* in each.

TABLE V.

SWEDISH TURNIPS.

Grown year after year on the same land, Barnfield, Rothamsted.

Proportion of leaf to root, and selected constituents in root and leaf,

Per cent. and per acre.

Mean of plots 4, 5, and 6; four years, 1849-1852.

	SERIES 1.	SERIES 3.	SERIES 4.	SERIES 5.	
	No Nitrogenous Manure.	Ammonium Salts = 43 lbs. Nitrogen.	Ammonium Salts and Rape Cake = 141 lbs. Nitrogen.	Rape Cake = 98 lbs. Nitrogen.	
LEAF TO 1000 ROOT.					
	69.0	61.8	78.5	65.5	
PER CENT.					
Dry Matter {	In root	11.59	11.51	10.54	10.89
	In leaf	13.81	13.08	12.97	13.19
Nitrogen {	In root	1.40	1.69	2.19	1.84
in Dry {	In leaf	3.95	4.07	4.11	4.00
Mineral Matter {	In root	4.38	4.49	4.83	4.66
in Dry {	In leaf	12.16	11.85	10.54	10.59
PER ACRE, lbs.					
Dry Matter {	In root	1879	2245	2840	2769
	In leaf	154	166	270	227
	Leaf + or - root	- 1725	- 2079	- 2570	- 2542
Nitrogen {	In root	26	38	62	51
	In leaf	6	7	11	9
	Leaf + or - root	- 20	- 31	- 51	- 42
Mineral Matter {	In root	83	102	139	130
	In leaf	19	20	29	24
	Leaf + or - root	- 64	- 82	- 110	- 106

It is seen that, instead of 300 to 600 parts of leaf for 1000 of root, as in the White or Common Turnip, we have, with the Swedish

Turnip, in no case 100 of leaf to 1000 of root. The highest proportion is $78\frac{1}{2}$ to 1000, and this is with the highest nitrogenous manuring, and the most luxuriant crops.

It is further seen that the percentage of dry matter in the root ranged from $10\frac{1}{2}$ to $11\frac{1}{2}$, whilst in the White Turnip it averaged only about 8 per cent. We have, therefore, not only a larger proportion of edible root, but that root contains a larger proportion of solid matter or food material.

As with the Norfolk White, however, so also with the Swedish Turnip, the leaf contains a much higher percentage of dry substance than the root, and that dry substance contains a much higher percentage of both nitrogen and total mineral matter than does the dry substance of the root.

The lower division of the Table shows, especially when compared with the corresponding particulars relating to the Common Turnip, how very different are the two crops in some very important respects. Thus, with the Swedish Turnip we have, with the highest manuring, fully one and a half time as much dry substance per acre in the root; that is one and a half time as much food produced per acre, as with the Common Turnip. We have a quite insignificant amount of matter accumulated and remaining in the leaf, that is for the most part only serving as manure again.

Of the nitrogen again, there is, under all conditions of manuring, even those giving the greatest luxuriance, a very small proportion remaining in the leaf. The same is the case with the total mineral matter.

The question obviously suggests itself, if the Swedish Turnip has all these advantages over the numerous varieties of the so-called Common Turnip, why are these ever grown? why not always the Swedish Turnip?

In the first place, soil and season have to be taken into account. Then the economy of the farm requires that descriptions should be selected that can not only be sown in due succession, but which will mature at different periods, so as to supply food for stock in due succession, and also frequently to get the crop early off the land, to leave it free for some other crop. Again, a comparatively large proportion of leaf serves as protection against frost while the crop is still in the field; and the storing qualities of the root have to be considered in connection with the character of the seasons of the locality. For example, on the light soils of Norfolk, which are very favourable for the development of root, and but little for that of leaf, and where the roots can be largely consumed by sheep on the land, without injury to its mechanical condition, the Swedish Turnip is the predominant root. In the north east and east of Scotland, on the other hand, several varieties of Yellow Common Turnips are grown in much larger proportion, and a large amount of leaf is not recognised as a disadvantage. And here it may be observed, that the higher the nitrogenous manuring, and the heavier the soil, the greater is the tendency to produce a large

amount of leaf. Further, as a rule, the larger the amount of leaf remaining vigorous at the time the crop is taken up, the less fully ripe will be the roots; and, within limits, it is desirable with a view to the storing qualities of the root, that it should not be too ripe.

After the four crops of Swedish Turnips had been taken from the land, barley was grown for three years in succession without any manure, in order, as far as possible, to equalise the condition of the various plots, as affected by the previous manuring.

It will suffice to say that the results clearly showed that there had been accumulation where rape-cake had been applied.

Then, for five years in succession (1856-60), Swedish Turnips were again grown on the comparatively exhausted plots, much on the same plan as before, but with smaller amounts of nitrogen supplied. No special interest attaches to the results over these five years for our present purpose.

I now pass to the consideration of the average results obtained over the next ten years, 1861-1870, again with Swedish Turnips. During this period larger quantities of nitrogen were again applied; but for mineral manure superphosphate of lime was used alone, that is without any further addition of either potash, soda, or magnesia. The average produce per acre on the different plots over the 10 years is given in Table VI.

TABLE VI.

SWEDISH TURNIPS.

Grown year after year on the same land, Barnfield, Rothamsted.

Results showing the effects of exhaustion and Manures.

Mean of ten seasons, 1861-'70. Manures and Produce per acre per annum.

	SERIES 1.	SERIES 2.	SERIES 3.	SERIES 4.	SERIES 5.
	No Nitrogenous Manure.	Sodium Nitrate = 86 lbs. Nitrogen.	Ammonium Salts = 86 lbs. Nitrogen.	Ammonium Salts and Rape Cake = 184 lbs. Nitrogen.	Rape Cake = 98 lbs. Nitrogen.

WITHOUT MINERAL MANURE.

	Tons. Cwts.	Tons. Cwts.	Tons. Cwts.	Tons. Cwts.	Tons. Cwts.
Roots ...	0 11	1 1	0 13	4 9	4 15
Leaves ...	0 3	0 5	0 3	1 0	0 18
Total ...	0 14	1 6	0 16	5 9	5 13

WITH SUPERPHOSPHATE OF LIME (Plots 4, 5, and 6).

	2 9	5 8	4 9	7 9	6 8
Roots ...	0 9	1 0	0 17	1 14	1 3
Leaves ...					
Total ...	2 18	6 8	5 6	9 3	7 11

The results of these experiments are little more than confirmatory of those which have gone before ; but the amounts of produce are throughout on a lower level. This can only in part be attributed to the exclusion of potash from the manures. It is doubtless mainly due to the incidental circumstance that in growing the same description of crop, with the same comparatively limited and superficial root-range, for so many years in succession, the surface soil became less easily worked, and the tilth, so important for turnips, was frequently unsatisfactory ; whilst for want of variety and depth of root-range of the crop, a somewhat impervious pan was formed below.

This fact is, however, of itself of considerable interest, as indicating one important and very beneficial influence of a rotation of crops. Indeed, we shall presently see, that even the change to another description of root-crop, with a totally different and much more extended root-range, is accompanied with a much increased production over a given area by the use of the same manures.

Looking to the Table (VI.), it is seen that there are now five series of Plots instead of only four ; nitrate of soda being applied on series 2, in amount supplying the same quantity of nitrogen as in the ammonium-salts on series 3. The result is a greater produce of both root and leaf than with the ammonium-salts.

The superphosphate alone (see lower division of column 1) gives less produce than the mineral manures in the series of four years before considered, doubtless to a great extent owing to the still further exhaustion of the available nitrogen of the surface soil. In fact the surface soils in question showed, on analysis, lower percentages of nitrogen than those of any other experimental field at Rothamsted—a result which is quite consistent with the fact of the large amount of feeding-root distributed through the surface soil by the growing turnip.

Again, consistently with this supposition, and with the results that have gone before, there is still very marked, but somewhat reduced effect, from all the nitrogenous manures ; and again, the amount of leaf is very small, but it is the greater the higher the nitrogenous manuring, and the greater the luxuriance of growth.

Table VII. shows the proportion of leaf to 1000 of root ; also the percentages of dry matter, and of nitrogen and mineral matter in the dry matter ; and, as before, the amounts of each per acre, in the roots and in the leaves.

With the soil gradually becoming closer, and less favourable for root development, the proportion of leaf to root is somewhat higher.

It should be explained that the percentages given in parentheses are not the results of direct determinations in each particular case, but are deduced from comparable results. They are, however, undoubtedly near enough to the truth for the purpose of the present illustrations.

Again, we see the much higher percentage of dry substance in the leaf than in the root ; also much higher percentages of nitrogen, and of total mineral matter, in the dry substance of the leaf.

TABLE VII.

SWEDISH TURNIPS.

*Grown year after year on the same land, Barnfield, Rothamsted.*Proportion of leaf to root, and selected constituents in root and leaf,
Per cent. and per acre.

Mean of Plots 4, 5, and 6; ten years, 1861-1870.

		SERIES 1.	SERIES 2.	SERIES 3.	SERIES 4.	SERIES 5.
		No Nitrogenous Manure.	Sodium Nitrate = 86 lbs. Nitrogen.	Ammonium Salts = 86 lbs. Nitrogen.	Ammonium Salts and Rape Cake = 184 lbs. Nitrogen.	Rape Cake = 98 lbs. Nitrogen.
LEAF TO 1000 ROOT.						
		184	185	191	228	180
PER CENT.						
Dry Matter	In root ..	12·04	11·01	11·32	10·94	10·83
	In leaf ...	14·93	14·46	14·24	13·78	14·66
Nitrogen in Dry	In root...	(1·40)	(1·69)	(1·69)	(2·19)	(1·84)
	In leaf ...	(3·95)	(4·07)	(4·07)	(4·11)	(4·00)
Mineral in Dry	In root ..	4·55	5·38	4·71	5·10	5·03
	In leaf ...	11·64	10·62	12·23	11·54	11·27
PER ACRE, lbs.						
Dry Matter.	In root... ..	629	1285	1084	1777	1511
	In leaf	146	320	268	498	376
	Leaf + or - root	- 483	- 965	- 816	- 1279	- 1135
Nitrogen	In root... ..	8·8	21·7	18·3	38·9	27·8
	In leaf	5·8	13·0	10·9	20·5	15·1
	Leaf + or - root	- 3·0	- 8·7	- 7·4	- 18·4	- 12·7
Mineral Matter.	In root... ..	28·9	71·1	53·6	94·2	76·6
	In leaf	16·8	33·1	32·5	57·5	41·9
	Leaf + or - root	- 12·1	- 38·0	- 21·1	- 36·7	- 34·7

Looking to the lower division of the Table, it is seen that there is here again, under all conditions of manuring, much more solid matter *per acre*, in the root than in the leaf. There is also more nitrogen, and more total mineral matter, accumulated in the root; though the proportion of the nitrogen which is accumulated in the leaf is higher than in the previous experiments.

EXPERIMENTS WITH SWEDISH TURNIPS IN ROTATION.

I have now to call attention to illustrations drawn from results of experiments in which Swedish Turnips were grown under conditions

much more nearly allied to those of their cultivation in ordinary farm practice, namely, when grown in the ordinary four-course rotation of—roots ; barley ; clover, beans, or fallow ; and wheat.

The experiments in question commenced in 1848, and they are still in progress, so that the tenth course of four years each, making 40 years in all, is completed with the harvest of this year—1887 ; and the tenth season of turnips was in 1884.

The area under experiment is two and a half acres, divided into three main divisions, respectively under the following conditions as to manuring :—

- 1.—Unmanured from the commencement.
- 2.—Superphosphate of lime alone, applied only for the turnip-crop, commencing each course ; that is once every four years. For the tenth course, however, salts of potash, soda, and magnesia, have been applied as well as superphosphate.
- 3.—A complex manure, only applied every fourth year, that is for the turnip crop, and comprising superphosphate of lime, salts of potash, soda, and magnesia, ammonium-salts, and rape-cake, and supplying about 140 lbs. of nitrogen per acre for each course.

This complex manure was designed to be, in a great measure, a substitute for farm-yard manure, and was used instead of it, in order that the amount of the different constituents supplied might be more accurately known.

It should be further explained that, from one-half of each of the three plots, the turnips, with their leaves, were carted off the land, whilst they were consumed by sheep (or cut and spread) on the other half.

Table VIII. shows the produce of Swedish Turnips, roots, leaves, and total, on each of the two portions of each of the differently manured plots each year.

The first point to remark is that, excepting in the first year, when the land was in somewhat high condition, the produce of roots without manure was, even in rotation, quite insignificant—not amounting to an average of 1 ton per acre over the subsequent years.

Superphosphate of lime alone gives much more—on the average, from eight to nine tons per acre.

This great increase is due largely to the very great development of feeding root within the surface soil under the influence of the phosphatic manure ; and the necessary nitrogen, beyond the small amount of combined nitrogen annually coming down in rain and the minor aqueous deposits from the atmosphere, has doubtless been gathered, under the influence of this increased root development, from the previous accumulations within the soil itself.

By the complex manure, however, supplying, besides phosphate, other mineral constituents, and also a large amount of nitrogen, the crops are still further much increased. There were, indeed, in several cases about, or more than, 20 tons of roots per acre.

TABLE VIII.

SWEDISH TURNIPS.

Grown in four-course rotation, Turnips, Barley, Clover or Beans, and Wheat, Agdell Field, Rothamsted.

Ten Courses. Manured for the Turnips only.

QUANTITIES PER ACRE.

	CARTED OFF THE LAND.			FED ON THE LAND.		
	Un-manured.	Super-phosphate. (1)	Mixed Manure.	Un-manured.	Super-phosphate. (1)	Mixed Manure.
ROOTS.						
	Tons. Cwts.	Tons. Cwts.	Tons. Cwts.	Tons. Cwts.	Tons. Cwts.	Tons. Cwts.
1848	8 15½	14 12	19 14½	8 17½	17 5	21 9
1852	1 6	11 3½	19 16½	0 19½	12 10½	19 6
1856	1 12	6 16	16 13½	1 0½	9 16	17 1½
1860	0 1	1 9½	4 7½	0 1	1 18½	3 12
1864	0 8½	3 8	8 16½	0 8½	3 18½	8 8½
1868	Crop failed.					
1872	1 14½	8 10½	16 19½	1 9½	9 10½	16 10
1876	0 17½	9 8½	17 16	1 1	11 5½	17 19½
1880	0 14	9 19½	21 19½	1 1	11 3½	22 6½
1884	0 5	8 13½	14 6½	0 12	10 6	14 0½
Means of 9 Courses }	1 14½	8 4½	15 12½	1 14½	9 14½	15 12½
LEAVES.						
1848	0 19½	1 15	2 6½	1 0½	1 19½	2 6½
1852	0 4½	1 0½	1 16½	0 3½	1 2	1 13
1856	0 2½	0 7½	0 12½	0 1½	0 14½	0 11½
1860	(6½ lbs.)	0 1½	0 3½	(5 lbs.)	0 1½	0 4½
1864	0 0½	0 4½	0 8½	0 1	0 4½	0 8½
1868	Crop failed.					
1872	0 8½	0 17½	1 15½	0 7½	0 19½	1 19
1876	0 5	1 8½	2 15½	0 5	1 7½	3 3
1880	0 2½	0 11½	2 3½	0 3	0 11	1 18½
1884	0 3½	1 0½	3 3½	0 5	1 3	3 3½
Means of 9 Courses }	0 5½	0 16½	1 13½	0 5½	0 18½	1 14½
TOTAL PRODUCE.						
1848	9 15	16 7	22 1	9 18½	19 4½	23 15½
1852	1 10½	12 3½	21 13	1 2½	13 12½	20 19
1856	1 14½	7 3½	17 6½	1 1½	10 10½	17 13
1860	0 1	1 10½	4 10½	0 1	2 0½	3 16½
1864	0 9½	3 12½	9 5	0 9½	4 3½	8 17½
1868	Crop failed.					
1872	2 2½	9 8	18 15½	1 17½	10 10	18 9
1876	1 2½	10 16½	20 11½	1 6	12 13½	21 2½
1880	0 16½	10 11½	24 2½	1 4	11 14½	24 5
1884	0 8½	9 13½	17 10	0 17	11 9	17 4½
Means of 9 Courses }	2 0	9 0½	17 6½	1 19½	10 13½	17 6½

(1) For the tenth course, salts of potash, soda, and magnesia, as well as superphosphate.

But, under each condition as to manuring, there is very great variation in amount of growth from year to year, according to the characters of the seasons. In 1868, indeed, the crop entirely failed on all the plots, although the seed was sown twice. Again, whilst the complex manure yielded about 22 tons of roots in 1880, the very same manure gave only about 4 tons in 1860; the average yield over the nine years being about $15\frac{1}{2}$ tons. Against this, the average yield by superphosphate of lime alone was about 9 tons, and without any manure only about $1\frac{1}{2}$ tons.

With regard to the comparatively large amount of produce by superphosphate of lime alone, it is of interest to state, in passing, that there is, perhaps, no agricultural practice by which what is termed the *condition* of land, that is the readily available fertility due to recent accumulations, can be to so great an extent exhausted by one crop, as by growing turnips by superphosphate of lime alone; provided, of course, that the season is favourable.

I must not enter into any detail as to the climatal characters of the individual seasons yielding such very different amounts of produce; but it may be stated that the results, like those before referred to, show that not only a considerable amount, but considerable continuity, of rain is required to favour the continuous accumulation of material by these succulent crops, whose office it is to form a large amount of comparatively crude and immature products. These conditions as to moisture being fulfilled, fairly average, or even rather over average temperatures may not be adverse, provided the plant has secured a good start, and has attained a fair amount of vigour. Under the same circumstances, too, lower than average temperatures may still be favourable for such growth.

Table IX. shows for these Swedish Turnips grown in an ordinary course of rotation, on the same plan as in other cases, the proportion of leaf to root, and the percentages, and the amounts per acre, of dry matter, and of certain constituents of the dry matter, in the root, and in the leaf, respectively; and there are now given, besides the percentages and the amounts per acre, of nitrogen and of total mineral matter, those of potash and of phosphoric acid also.

In the first line of figures it is seen that the average amount of leaf to 1000 root is, without manure, relatively high, there being practically no root development. With superphosphate of lime alone, there was little luxuriance, but special tendency to root-formation, and the proportion of leaf is low. With the mixed (mineral and nitrogenous) manure, and great luxuriance, there is a larger proportion of leaf. But in all cases there is a comparatively small proportion, and as before very much less than in the case of the common or White Turnip.

In the next division of the Table are given the *percentages* of dry or solid matter in the root and in the leaf; and the percentages of nitrogen, total mineral constituents, potash, and phosphoric acid, in the dry matter, of root and leaf.

As in the case of the crop when grown year after year on the same

TABLE IX.

SWEDISH TURNIPS.

*Grown in four-course Rotation. Agdell Field, Rothamsted.*Proportion of leaf to root, and selected constituents in root and leaf,
Per cent. and per acre.

Mean of 9 courses, 1848, '52, '56, '60, '64, '72, '76, '80, and '84.

		Un- manured.	Super- phosphate.	Mixed Manure.
LEAF TO 1000 ROOT.				
		150	96	109
PER CENT.				
Dry Matter ...	In root	12.40	11.30	10.61
	In leaf	16.73	15.24	14.80
Nitrogen in Dry	In root	2.82	1.89	2.32
	In leaf	3.90	3.95	4.18
Mineral Matter in Dry... ..	In root	4.52	4.54	5.65
	In leaf	12.91	11.94	11.92
Potash in Dry ...	In root	1.45	1.40	2.31
	In leaf	2.04	1.73	2.94
Phosphoric Acid in Dry.. ...	In root	0.37	0.53	0.58
	In leaf	0.55	0.85	0.90
PER ACRE, lbs.				
Dry Matter ...	In root	473	2281	3689
	In leaf	98	279	504
	Leaf + or - root	- 375	- 2002	- 3185
Nitrogen	In root	11.6	40.5	81.8
	In leaf	3.8	10.7	21.2
	Leaf + or - root	- 7.8	- 29.8	- 60.6
Mineral Matter ..	In root	21.4	100.9	205.1
	In leaf	12.0	31.0	59.7
	Leaf + or - root	- 9.4	- 69.9	- 145.4
Potash	In root	6.8	31.0	83.8
	In leaf	1.9	4.5	14.7
	Leaf + or - root	- 4.9	- 26.5	- 69.1
Phosphoric Acid	In root	1.7	11.6	20.9
	In leaf	0.5	2.2	4.5
	Leaf + or - root	- 1.2	- 9.4	- 16.4

land by artificial manures, so now when grown only once in four years in an ordinary course of rotation, and in one case with a complex manure, mineral and organic, and including a liberal supply of nitrogen, thus fairly representing farmyard manure, we have considerably higher percentages of solid matter in the leaf than in the root. We have, also, very much higher percentages of nitrogen and of total mineral matter, and notably higher percentages of both potash and phosphoric acid, in the dry matter of the leaf than in that of the root.

It will be observed that the unmanured roots and leaves show abnormally high percentages of dry matter, and the roots an abnormally high percentage of nitrogen in their dry substance. The percentage of phosphoric acid in the dry substance of both leaf and root was, however, much lower than in either of the other experiments; and as the next results show, it was largely for want of phosphoric acid that the growth was so restricted.

The crops grown by superphosphate of lime alone would be fully ripe, and much riper than those grown by the complex manure, and accordingly both root and leaf show higher percentages of dry substance; whilst, owing to the want of supply of any nitrogen by manure, the superphosphate roots contain a relatively low percentage of nitrogen in their dry substance.

The amounts of constituents per acre, in root and leaf, are given in the lower division of the Table. As in the other cases with Swedish Turnips, there is, under each condition of manuring, and in the case of each of the constituents enumerated, very much more per acre in the root than in the leaf. Leaving the results without manure out of the question, as entirely abnormal, it may be observed that whilst the total produce (roots and leaves) by superphosphate of lime alone, contains less than 23 cwt. of solid matter per acre, that by the complex manure contains nearly 37½ cwt. Of the total solid matter per acre, rather more than ⅔ths of that grown by superphosphate of lime alone, and rather more than ⅔ths of the larger amount grown by the mixed manure, is accumulated in the edible roots.

About twice as much nitrogen was accumulated in the crop grown by the complex manure which supplied it, as by the superphosphate of lime alone; and in each case about ⅔ths of the total nitrogen was in food-product—the root.

There was also very much more of total mineral constituents, and especially of the functionally more important ones, potash and phosphoric acid, taken up under the influence of the full supply, and more luxuriant growth; and, of each of these, several times as much was contained in the root as in the leaf.

These further illustrations in regard to Swedish turnips, therefore fully confirm those which have gone before, in showing that a very much larger proportion of the substance grown is accumulated in the root than in the leaf, than is the case with the common turnips. In fact, all the evidence goes to show that whilst in the case of the common turnips a very large amount of the matter grown only serves

for manure again, in that of the Swedish turnips a very small proportion of the produce is useless as food for stock.

EXPERIMENTS WITH MANGEL WURZEL.

I have now to direct attention to root-crops of very different characteristics from those of the crops contributed by the Natural Order Cruciferae, and the genus *Brassica*, namely, to a variety of the *Beta vulgaris*, of the Natural Order Chenopodiaceae.

To this Order, and to this species, we owe the many varieties of feeding beet or Mangel-wurzel, and also many varieties of the Sugar-beet. As the Mangel-wurzel is a very important agricultural crop in this country, whilst the Sugar-beet is not, I shall only consider in any detail the results relating to the Mangel.

The results with both crops were obtained in the same field and on the same plots as those on which, first Norfolk Whites, and afterwards Swedish Turnips, were grown year after year on the same land, without manure, and with different descriptions of manure.

The last series of Swedish Turnips grown in that field were in the ten years 1861-1870; and it has been stated that by the continuous growth of the one description of crop, with one character and range of roots, the surface soil had become close, and a somewhat impervious pan was formed below it. After this the land was ploughed more deeply, and Sugar-beet was grown for five years in succession—1871 to 1875 inclusive. Since then, commencing in 1876, and continuing every year up to the present time, 1887, a period of 12 years, Mangel-wurzel has been taken. It is from results obtained in the field during the first eight years, and in the Laboratory during shorter periods, that I shall now draw my illustrations.

Table X. shows, in the same form as previously for the Turnips grown in the same field, the manures applied per acre per annum, and the average produce per acre per annum, on each plot, over the eight years 1876 to 1883 inclusive.

It will be seen that results are now given for six instead of for only four main plots; those for two plots with farm-yard manure being added. Each main plot is, as before, divided into five. The first column gives the results where no cross-dressings of artificial nitrogenous manure were used. The second those obtained with a cross-dressing of nitrate of soda in addition; the third with ammonium-salts in addition; the fourth with ammonium-salts and rape-cake added; and the fifth with rape-cake only added. The upper division shows the produce of roots, the middle division that of the leaves, and the lower division the total produce, roots and leaves together.

A glance at the Table (X.) shows that the produce of roots of the Mangel-wurzel, where nitrogenous manures were applied, is on a much higher level than that of either common or Swedish Turnips; and there is also much more leaf. Speaking generally, there is about twice as much produce of roots per acre as there was of Swedish Turnips with the same manures on the same plots, and the quantity of leaf is more than twice as great.

TABLE X.

MANGEL WURZEL.

Grown year after year on the same land, Barnfield, Rothamsted.

Results showing the effects of exhaustion and manures.

Means for 8 seasons, 1876-'83.

Manures and Produce per acre per annum.

Plot Nos.		SERIES 1. No Artificial Nitrogenous Manure.	SERIES 2. Sodium Nitrate = 86 lbs. Nitrogen.	SERIES 3. Ammonium Salts = 86 lbs. Nitrogen.	SERIES 4. Ammonium Salts and Rape Cake = 184 lbs. Nitrogen.	SERIES 5. Rape Cake = 98 lbs. Nitrogen.
ROOTS.						
1	Farmyard Manure ...	Tns. cwt. 15 10	Tns. cwt. 21 9	Tns. cwt. 22 6	Tns. cwt. 25 1	Tns. cwt. 22 8
2 {	Farmyard Manure and Superphosphate ...	15 13	23 10	22 1	24 13	22 17
3	No Mineral Manure ...	4 9	13 17	7 7	11 7	11 6
5	Superphosphate ...	5 2	16 18	9 10	12 8	12 17
6 {	Superphosphate and Potassium Sulphate ...	4 10	17 9	14 15	22 10	17 14
4 {	Superphos., Pot., and Magnesium Sulphates, and Sodium Chloride	5 14	19 10	16 1	25 14	19 13
	Means of 6 and 4 ...	5 2	18 10	15 8	24 2	18 14
LEAVES.						
1	Farmyard Manure ...	2 16	4 2	5 4	6 5	3 19
2 {	Farmyard Manure and Superphosphate ...	2 12	4 12	5 8	6 5	4 0
3	No Mineral Manure ...	1 0	3 5	3 0	4 2	2 18
5	Superphosphate ...	1 0	3 8	3 4	4 7	3 3
6 {	Superphosphate and Potassium Sulphate ...	0 18	3 2	2 15	5 8	2 14
4 {	Superphos., Pot., and Magnesium Sulphates, and Sodium Chloride ..	1 2	3 14	2 15	5 4	3 1
	Means of 6 and 4 ...	1 0	3 8	2 15	5 6	2 17
TOTAL PRODUCE (ROOTS AND LEAVES).						
1	Farmyard Manure ...	18 6	25 11	27 10	31 6	26 7
2 {	Farmyard Manure and Superphosphate ...	18 5	28 2	27 9	30 18	26 17
3	No Mineral Manure ...	5 9	17 2	10 7	15 9	14 4
5	Superphosphate ...	6 2	20 6	12 14	16 15	16 0
6 {	Superphosphate and Potassium Sulphate ...	5 8	20 11	17 10	27 18	20 8
4 {	Superphos., Pot., and Magnesium Sulphates, and Sodium Chloride	6 16	23 4	18 16	30 18	22 14
	Means of 6 and 4 ...	6 2	21 18	18 3	29 8	21 11

The Mangel seed is sown earlier, and the plant has a longer period of growth. It has a much more deeply penetrating tap root, throws out a less proportion of its feeding roots near the surface, and exposes a comparatively large area of leaf to the atmosphere. With its more extended root-range, it is less dependent on continuity of rain when growth is once well established; and it bears or rather requires for full growth, a higher temperature than the turnip. The midland, eastern, and southern divisions of the country are therefore much more suitable for the crop than the north-west or north of England, or than Scotland, where it is comparatively little grown. But, where the soil and climate are suitable, very much larger crops can be obtained than of Turnips. The Mangel requires, however, very heavy dressings of farm-yard manure if it is to yield full crops.

The Table X. (p. 21) shows that with farm-yard manure alone, at the rate of 14 tons per acre per annum, there was an average produce of about $15\frac{1}{2}$ tons of roots per acre, and that the addition of superphosphate of lime increased it very little. This result compared with that obtained with Turnips is quite consistent with the difference in the character and range of the feeding-roots of the two crops; and it is also quite accordant with common experience, which has shown that superphosphate is very much less generally beneficial when applied to Mangels.

Notwithstanding the amount of farm-yard manure employed would supply annually about 200 lbs. of nitrogen per acre, it is seen that the addition of specially nitrogenous manures greatly increases the crops; and where the nitrogen is applied in the very rapidly available condition as in nitrate of soda, superphosphate of lime is not without effect. In the nitrate of soda or ammonium-salts, 86 lbs. of nitrogen is supplied per acre annually, and the crops are increased by nearly one-half. Where rather more nitrogen is applied, in rape-cake, in which however it exists in a less rapidly available condition, the amount of increase is much the same as with the nitrate or the ammonium-salts; but with the rape-cake there will be more unexhausted residue remaining in the soil.

Where both rape-cake and ammonium-salts are used in addition to the farm-yard manure, there is an average of about 25 tons of roots per acre per annum over the eight years.

Without manure, or with purely mineral manures, the produce of this more powerfully rooting plant is much higher than was previously obtained with Swedish Turnips on the same plots, notwithstanding that the land had become more exhausted so far as nitrogen is concerned.

The addition of the nitrogenous to the mineral manures in some cases more than quadrupled the produce. A given quantity of nitrogen in the more rapidly available condition, as in nitrate of soda, yielded more increase of crop than the same amount as ammonium-salts.

With the comparatively limited growth of turnips, potash manures had little effect; but here, after years of further exhaustion of the potash within the soil itself, and with so much more vegetable matter produced, the deficiency of potash where it has not been applied is

rendered very obvious by the much less produce obtained where superphosphate was used without potash, than where potash was also supplied in the manure.

Even with the artificial manures, the average produce in several cases approaches 20 tons of roots per acre; in one case where the largest amount of nitrogen was employed there was an average of $22\frac{1}{2}$ tons, and in another of nearly $25\frac{1}{2}$ tons per acre per annum.

Attention will be called to the proportion of leaf to root further on, but before passing from Table X. it should be noticed that the actual quantity of leaf per acre is comparatively large. Thus it amounts, on some of the farm-yard manure plots, to five or six tons, or even more, which, for the most part, returns to the land at once as manure.

Lastly, on several plots, there was an average annual total produce, root and leaf together, of more than 30 tons. The very great power of utilising manure and producing vegetable substance possessed by the Mangel is thus strikingly illustrated. Indeed, the results amply demonstrate that, great as is the capability of luxuriance of the plant, its full development is pre-eminently dependent on large supplies by manure.

It has been assumed by some, however, that by virtue of the large amount of leaf-surface which root crops expose to the atmosphere, they are enabled to obtain a large amount of their nitrogen from that source. It is further assumed that, if a small quantity of nitrogenous manure is supplied, so as to favour the early development of the plant, it will then obtain the remainder from the atmosphere. The results given in Table XI. afford pretty conclusive evidence against such a view.

There is there given the average produce of Mangel-wurzel, roots and leaves, over five years:—

- 1.—By superphosphate of lime and potassium sulphate.
- 2.—By the same mineral manures, with, in addition, ammonium-salts, supplying 7·8 lbs. nitrogen per acre per annum.
- 3.—The same mineral manures, and ammonium-salts, supplying 86 lbs. nitrogen per acre per annum.

TABLE XI.

MANGEL WURZEL.

Manures and Produce per acre per annum. Five years, 1876-1880.

	ROOTS.	LEAVES.	TOTAL.
	Tons. cwt.	Tons. cwt.	Tons. cwt.
1. Superphosphate of Lime and Potassium Sulphate	4 10	1 0	5 10
2. As 1, and $36\frac{1}{2}$ lbs. Ammonium Salts (= 7·8 lbs. Nitrogen)	6 0	1 6	7 6
3. As 1, and 400 lbs. Ammonium Salts (= 86 lbs. Nitrogen)	14 0	2 16	16 16

Thus, the annual application of 7·8 lbs. of nitrogen has increased the crop by only 30 cwt. of roots per acre per annum; and the

increased yield of nitrogen in the crop was even somewhat less than that supplied in the manure. The application of 86 lbs. of nitrogen, has, however, increased the crop of roots by 160 cwt. more; or by 190 cwt. in all.

It is obvious from these results that the application of the small amount of nitrogen did not enable the plant to take up any from the atmosphere, and that it required a further supply of nitrogen by manure to obtain a further increase of crop.

It is true, as already said, that a small amount of combined nitrogen annually comes down from the atmosphere in rain, and the minor aqueous deposits; but it cannot be doubted that, beyond this, the source of the large amount of nitrogen of root crops is the store of it within the soil, whether this be due to less recent accumulations, or to direct supply by manure. On the other hand, the large amounts of produce obtained by the aid of nitrogenous manures, on plots to which no carbonaceous manure has been applied for about 40 years, is evidence that the atmosphere is at any rate the chief, if not the exclusive source, of the carbon of the crops.

Let us now turn to the question of the actual proportion of leaf to root, and to the distribution of certain constituents in the root and the leaf, respectively.

The results relating to these points will be found in Table XII.

The first line of figures shows that the proportion of leaf to 1000 root ranged from 175 to 243, and that it was the highest with the highest nitrogenous manure, and greatest luxuriance. The proportion of leaf is thus considerably higher than in the case of Swedish turnips, but very much lower than with common turnips. Although each of the various descriptions of root has, so to speak, its own range as to proportion of leaf, yet with the same description there will generally be the more, the heavier the soil, the wetter the season, and the higher the nitrogenous manuring. The proportion will also be higher the less matured the crop at the time of taking up.

Referring now to the percentage composition of the Mangel root and leaf, it is to be observed that whilst with Turnips there was a much higher percentage of solid matter in the leaf than in the root, there is, in Mangels, a considerably higher percentage in the root than in the leaf. The percentage of dry or solid substance in the Mangel root is, in fact, considerably higher than that in the Swedish turnip root, whilst the percentage in the Mangel leaf is much lower than in the Turnip leaf. The question suggests itself, how far this may be due to more complete exhaustion of the leaf in the accumulation of the larger amount of reserve material in the root?

The percentage of nitrogen in the dry substance of the root, is much the higher, the higher the nitrogenous manuring; and it will be seen further on that, beyond comparatively narrow limits, a high percentage of nitrogen may even be a disadvantage, so far as the feeding quality of the root is concerned. As in the case of the Turnips, the percentage of nitrogen is very much higher in the dry substance of

the leaf than in that of the root; and it is as a rule the higher in the leaf the less mature the root.

TABLE XII.

MANGEL WURZEL.

Grown year after year on the same land, Barnfield, Rothamsted.

Proportion of leaf to root, and selected constituents in root and leaf,
Per cent. and per acre.

Means of Plots 4, 5, and 6. Six years, 1878-1883.

	SERIES 1. No Nitrogenous Manure.	SERIES 2. Sodium Nitrate = 86 lbs. Nitrogen.	SERIES 3. Ammonium Salts = 86 lbs. Nitrogen.	SERIES 4. Ammonium Salts and Rape Cake = 184 lbs. Nitrogen.	SERIES 5. Rape Cake = 98 lbs. Nitrogen.
LEAF TO 1000 ROOT.					
	200	183	217	243	175
PER CENT.					
Dry Matter {					
In root	14.99	12.52	13.70	12.79	13.56
In leaf	10.43	9.77	10.06	10.10	10.92
Nitrogen {					
In root	0.88	1.39	1.25	1.64	1.26
In leaf	2.55	2.94	2.86	3.29	2.88
Mineral Matter {					
In root	5.48	7.19	6.28	6.91	6.26
In leaf	20.16	19.68	19.66	19.21	18.65
PER ACRE, lbs.					
Dry Matter {					
In root... ..	1504	4665	3823	5444	4691
In leaf	210	663	614	1033	667
Leaf + or - root	- 1294	- 4002	- 3209	- 4411	- 4024
Nitrogen {					
In root... ..	12.9	63.8	45.7	84.7	57.7
In leaf	5.4	19.5	17.6	34.0	19.2
Leaf + or - root	- 7.5	- 44.3	- 28.1	- 50.7	- 38.5
Mineral Matter {					
In root... ..	81.1	331.3	243.0	379.5	292.1
In leaf	41.4	130.2	119.6	198.0	121.8
Leaf + or - root	- 39.7	- 201.1	- 123.4	- 181.5	- 170.3

It is remarkable that the percentage of mineral matter is about three times as high in the dry substance of the leaf as in that of the root. Further, according to published analyses of the ash of Mangel-root and Mangel-leaf, the ash of the leaf contains a much lower percentage of potash, but about the same percentage of phosphoric acid as that of the root. But owing to the lower percentage of organic

substance in the leaf, and the much higher percentage of ash in the dry substance, the percentage of both potash and phosphoric acid will be much higher in the dry substance of the leaf than in that of the root.

The lower division of the Table XII (p. 25) shows that the amount of dry or solid substance per acre, in the food-product of the crop, the root, ranges from about $\frac{2}{3}$ ds of a ton without nitrogenous manure, to $2\frac{1}{3}$ rd tons with the highest nitrogenous manure; and in conjunction with this larger amount there is nearly $\frac{1}{2}$ a ton of dry substance in the leaf.

We have here a striking illustration of how greatly dependent is the amount of carbon assimilated from the atmosphere over a given area, on the amount of nitrogen available to the plant within the soil. The total quantity of dry substance produced by the highest nitrogenous manure was nearly three tons per acre, which would contain considerably more than one ton of carbon; indeed the amount of carbon assimilated in excess of that without nitrogenous manure was not much less than one ton per acre. This is obtained by the leaves from the small proportion of carbonic acid existing in the atmosphere, which does not amount to more than one part of carbon as carbonic acid to 10,000 of air.

The Table further shows that there is five, six, or seven times as much solid matter accumulated in the edible root as in the leaf. Again, notwithstanding the much higher percentage of nitrogen in the dry substance of the leaf than in that of the root, there is, owing to the small proportion of leaf, two, three, or more times as much nitrogen per acre in the root as in the leaf. And again, notwithstanding the very high percentage of mineral matter in the dry substance of the leaf, there is, owing to the small proportion of the leaf, only about half as much total mineral matter per acre in the leaf as in the root. Lastly, so far as can be judged, very much more of the potash of the crop, and much more of the phosphoric acid also, will be in the root than in the leaf.

NITROGEN RECOVERED IN INCREASE OF CROP FOR 100 SUPPLIED IN MANURE.

The next point to consider is—what proportion of the nitrogen of the manure, which is shown to be so effective, is recovered in the increase of the crop of Mangels obtained by its use. Table XIII. gives particulars on this point.

The upper division of the Table shows the amounts of nitrogen supplied by manure per acre per annum to the plots of each of the four series (2, 3, 4, and 5), as already given in the former Tables; those of series 1 receiving no nitrogen.

It should be stated that on the plots of Series 1 with mineral, but without nitrogenous manure, there was obtained in the mangel roots an average of only about 13 lbs. of nitrogen per acre per annum. It should be remembered, however, that the plots yielding these very small amounts of nitrogen, even in the powerfully rooted Mangel crop, have now been under experiment with roots for more than 40 years, during which time they have received no nitrogen whatever by manure.

TABLE XIII.

MANGEL WURZEL.

Grown year after year on the same land, Barnfield, Rothamsted.

Nitrogen recovered in Increase of Crop (roots only) for 100 supplied in manure.

Average of 6 years, 1878-'83.

		SERIES 2.	SERIES 3.	SERIES 4.	SERIES 5.
		Nitrate of Soda.	Ammonium Salts.	Ammonium Salts and Rape Cake.	Rape Cake.
Nitrogen in Manure per acre per annum ...		lbs. 86	lbs. 86	lbs. 184	lbs. 98
NITROGEN RECOVERED IN INCREASE (OF ROOTS ONLY) FOR 100 SUPPLIED IN MANURE.					
3	No Mineral Manure ⁽¹⁾	44.2	23.3	21.1	33.7
5	Superphosphate	57.7	29.7	25.1	38.5
6	Superphosphate and Potassium Sulphate	58.1	44.5	45.5	51.8
4	Superphos., Pot., and Magnesium } Sulphates, and Sodium Chloride }	61.7	40.1	46.4	46.8
Means of Plots 6 and 4 ...		59.9	42.3	45.9	49.3

⁽¹⁾ Five years only, 1878-'82.

In fact, although in the earlier years the common and Swedish turnip yielded much more, yet in the recent years neither Sugar-beet nor Mangel-wurzel, with their greater powers of accumulation and growth, has removed so much nitrogen without nitrogenous manure as Wheat or Barley grown for between 30 and 40 years in succession on the same land without any artificial nitrogenous supply.

The actual amounts of nitrogen per acre in the roots, when nitrogen was supplied by manure, taking the average of the two mineral manured plots, 6 and 4, where potash was applied, were 64.4 lbs. by the application of 86 lbs. of nitrogen as nitrate of soda, and 49.3 lbs. with the same amount of nitrogen applied as ammonium-salts; thus showing much less effect from a given quantity of nitrogen as ammonium-salts than from an equal quantity as nitrate of soda. This is a general result in the average of seasons, but on the other hand the nitrogen of nitrate of soda is much more liable to loss by drainage, especially in wet seasons. With 98 lbs. of nitrogen in the comparatively slowly available condition as in rape-cake, the average amount in the produce of roots was 61.2 lbs.; and where the rape-cake and the ammonium-salts were used together, raising the supply of nitrogen to 184 lbs. per acre per annum, the average yield of nitrogen in the roots amounted to 97.5 lbs.

Deducting the amounts of nitrogen in the crops without nitrogenous manure, from those where it was supplied, we get the increase due to the supply; and the figures in the Table (XIII.) show, for each plot, and for each series representing the different conditions of supply of nitrogen, the increased amount of nitrogen in the roots for 100 supplied in the manure.

First comparing the four lines of figures with one another, it is seen that, under each condition as to nitrogenous supply, there is much less return for 100 supplied without, than with, the addition of mineral manures. Again, there is, under all conditions of nitrogenous supply, less, and in the cases of the ammonium-salts and the rape-cake very much less, of the supplied nitrogen recovered in the roots where only superphosphate of lime was applied, than where this was used in conjunction with potash, or potash, soda, and magnesia.

Comparing the average results of the two mineral-manured plots where potash was supplied (6 and 4), and nitrogen in the different conditions, as shown in the last line of the Table, it is seen that the amounts of nitrogen recovered as increase in the roots, for 100 supplied in manure, were :—

With Nitrate of soda - - - - -	59.9
With Ammonium-salts - - - - -	42.3
With Rape-cake - - - - -	49.3
With Rape-cake and ammonium-salts - -	45.9

Thus, even under the most favourable condition as to mineral supply, frequently less than 50 per cent. of the nitrogen supplied in these artificial manures was recovered in the increase of roots obtained by its use ; and even with the most effective of the nitrogenous manures, the nitrate of soda, only about 60 per cent. was so recovered.

It is obvious that the amount of nitrogen in the roots alone, by no means represents the total quantity assimilated per acre, but as that in the leaves is annually returned to the land as manure, it is clear that, taking the average over a number of years, it is only the amount in the roots that can be credited as immediate return from the manure employed.

Where, however, large amounts of organic matter are returned to the soil, such accumulation serves to keep up the *condition* of the land, so that more or less of the at first unrecovered constituents of the manure will remain for future crops.

Then as to the less return in the roots from a given amount of nitrogen supplied as rape-cake than as nitrate of soda, it should be borne in mind that, although the nitrogen of such organic manures only becomes comparatively slowly available, yet on that account the more remains in the soil as manure-residue for future crops.

Finally, the question obviously suggests itself—what is the result when, instead of these artificial manures, a large amount of nitrogen is supplied in farm-yard manure, which must always be liberally employed if heavy crops of Mangel-wurzel are to be grown ?

In the first place larger quantities of nitrogen would generally be applied per acre in farm-yard manure than in any of the artificial manures used in the experiments which have been described. So far as the results obtained on the farm-yard manure plots enable us to form an estimate, a much smaller proportion of that supplied would be taken up by the immediate crop than in the case of either nitrate of

soda or ammonium-salts, and even less than with rape-cake. But, an essential characteristic of farm-yard manure is, that it leaves a large but only slowly available residue for future crops. It is the nitrogen of the liquid dejections of the animals that is first rendered available within the soil, then that of the finely comminuted matter which passes intermixed with some secretions in the solid excrements, and finally that in the litter. It is, in fact, as already referred to, to the very large proportion of the constituents of the farm-yard manure applied for root-crops, which remains available for future crops, that an important part of the benefit of the growth of root-crops in rotation is to be attributed.

Indeed, it will be clearly seen from the evidence adduced, that the *Root-crops*, which are assumed to perform the office of restoring the condition of the soil for the growth of the crops grown in alternation with them, are themselves pre-eminently dependent on manure for their successful development. In fact, it is only when there is plenty of plant-food available in the soil, whether by accumulation, or direct supply by manure, that good root-crops can be obtained. But, these conditions being fulfilled, these crops, gross feeders as they are, are able to take up a large amount of matter from the soil, and to produce a large amount of vegetable substance; a large portion of which is valuable as food, whilst the remainder is valuable as manure again. Further, of the portion that is used as food for animals, by far the larger proportion of the constituents valuable as manure, is eventually recovered as such in the excrements of the animals.

That is to say, it is the great power of utilising the stores within the soil, due in some cases to accumulation, and in others to direct manuring, which these plants possess, growing and gathering nitrogen as they do after the period of its collection by the cereals, and the fact that it is only a very small proportion of their nitrogen, and of their mineral matter, which is carried off in the increase of the animals and so lost to the land, that constitute a great part of the value of the root crops in rotation. When, however, roots are consumed for the production of milk, the loss to the manure will be greater than when they are consumed by either store or fattening animals. Another very important element in the value of root-crops in rotation is, as already said, the opportunity they afford for the cleaning of the land.

It will be well here briefly to summarise the results which have been adduced, relating to the amounts of produce obtained with the different descriptions of root-crop, under the influence of the different descriptions of manure.

Confining attention in the first place to the produce of the roots per acre, there was, with each description of root, a very considerable increase obtained by the use of nitrogenous manures. The amounts of nitrogen supplied were not the same for each description of plant; but there can be no question that the amount, not only of total vegetable substance produced, but of stock-food yielded, was very much greater

from a given quantity of nitrogen when it was supplied to the Mangels, than when applied to the different descriptions of Turnip. Then, so far as the habit of growth of the different descriptions of plant is concerned, the Swedish Turnip shows the lowest proportion of leaf, the Mangel considerably more, and the common Turnip the most of all.

Having regard to the different characters of growth of the various descriptions of root, it will be of interest to direct attention to the extent to which the different kinds are cultivated in different divisions of the country. Table XIV. gives some information on this point, calculated from the Board of Trade Returns, of the area and produce of various agricultural crops.

TABLE XIV.

Root Crops.

Area under Turnips and Mangels in England and Wales, and in Scotland.

	Mean of 5 years, 1882-1886.			
	Actual area.		Per cent. of Total area.	
	England and Wales.	Scotland.	England and Wales.	Scotland.
	Acres.	Acres.	Per cent.	Per cent.
Turnips ⁽¹⁾	1,531,921	487,810	81·9	99·7
Mangels	337,521	1,432	18·1	0·3
Total	1,869,442	489,242	100·0	100·0

⁽¹⁾ Including Swedes.

It is seen that the average area under the various descriptions of Turnips is, in England and Wales, rather over $1\frac{1}{2}$ million acres; whilst in Scotland it is less than half a million acres. Again, the average area under Mangel-wurzel is 337,521 acres in England and Wales, and only 1,432 acres in Scotland. Further, whilst about 18 per cent. of the total area under roots in England and Wales is devoted to Mangels, less than a third of 1 per cent. of the total root-area in Scotland is devoted to that crop. It may be added that in neither division of the country has either the actual or the relative area fluctuated at all materially during the last ten years. The tendency is, however, to a slight diminution of total area under roots; and especially of Mangels in Scotland.

These facts afford sufficient evidence of the great influence of climate in determining what description of roots should be grown, and that this cannot be settled merely by a consideration of the amount of produce obtained by a given quantity of manure, of the proportion of the crop which is available as food for stock or only remains for manure again, or of the high or low percentage of solid matter in the food portion of the crop.

It has been pointed out that Turnips have a comparatively limited

root-range, and require both a considerable amount, and continuity, of rain, and only moderate temperatures; whilst the deeply and powerfully rooting Mangel is less dependent on continuity of rain after the plant has once got a good start, and will bear, or even requires, a warmer and drier autumn than Turnips.

Thus, whilst it is obviously desirable to extend the growth of the better descriptions of roots as far as possible, judgment must be exercised in the selection, so as to ensure that the kind chosen is suitable to the conditions of the soil and seasons of the locality.

Although Sugar-beet is not grown in this country as food for stock, some attempts have been made to grow it for the manufacture of sugar, or spirit, but hitherto they have failed. There can be little doubt, however, that Sugar-beet of good quality could be grown on favourable soils, and in favourable localities as to season. But it is essential to success that the manufacturer should hold the land, and adapt his rotation and manuring to the crop, and be able to command the quantity of roots he requires, and not be dependent, for both quantity and quality, on farmers in the neighbourhood, as has hitherto been the case, and as has hitherto been a material element in the failures that have occurred. So long, however, as heavy bounties are allowed on the export of beet-root sugar from European countries, a further obstacle stands in the way of the growth of Sugar-beet for the production of sugar in this country.

COMPOSITION OF DIFFERENT DESCRIPTIONS OF ROOTS; AND THEIR VALUE AS FOOD FOR STOCK.

Let us now revert to the question of the composition of the different descriptions of roots. The first points to consider are: the percentages of dry or solid matter, and of nitrogen, in the different roots, and the influence of the conditions of growth on these percentages. Next we have to consider: what are the most important non-nitrogenous food constituents formed in the roots? what is the average proportion of these in the different descriptions of root? and in what direction is the quantity they contain influenced by season and manuring? Lastly, the important question arises, what proportion of the total nitrogenous compounds in the roots is really food material?

First, as to the percentages of dry substance in the different descriptions of root.

Table III. (p. 7), shows that the different series of Norfolk White, or common Turnips, contained 8.54, 8.07, 7.66, and 7.96 per cent., or an average of only about 8 per cent. of solid matter in the roots; and the percentage is the lower the higher the manuring, and the greater the luxuriance, that is the less ripe the roots.

The four-year series of Swedish Turnips (Table V., p. 10) show 11.59, 11.51, 10.54, and 10.89 per cent. dry matter; and the ten-year series (Table VII., p. 14) show 12.04, 11.01, 11.32, 10.94, and 10.83 per cent. The Swedish Turnip shows, therefore, an average of about 11 per cent. of dry matter, or about 3 per cent. more than the Norfolk

White. There is again the lower percentage the higher the manuring, the greater the luxuriance, and the less ripe the roots.

The five series of Mangel-wurzel show (Table XII., p. 25) 14.99, 12.52, 13.70, 12.79, and 13.56 per cent. dry substance, that is a still higher percentage of solid matter than the Swedish Turnip. The average on the most normal plots may be taken at about 13, or about 2 per cent. higher than in the Swedish Turnip. And, as in the other cases, the percentage is directly connected with the condition as to luxuriance on the one hand, or ripeness on the other.

It may be mentioned that in Sugar-beet we found still higher percentages of solid matter, averaging on the more normal plots from 16 to 18 per cent., or from 3 to 5 per cent. higher than in the feeding Mangel. On this point it is of interest to add, that in recent years the most improved varieties cultivated for sugar-making, and grown under the most favourable conditions, contain even still much higher percentages of dry substance. Indeed, sometimes the roots yield as much as 20 per cent. of sugar!

Table XV. shows the average percentages, over four years, of dry matter, mineral matter (ash), nitrogen, and sugar, in the roots of each of the experimental Mangel plots.

The percentages of dry matter are, as already said, quite characteristic. They are much the highest in the roots of Series 1 with no artificial nitrogenous manure, that is with the smallest crops; and they are much the lowest in those of Series 2 and 4, in the one case with the nitrogen supplied in the most active condition, as nitrate of soda, and in the other with the greatest amount of it, indeed an excess, in the manure, and accordingly the greatest luxuriance, the largest crops, and the least matured condition of the roots.

The second division of the Table shows that the mineral matter constitutes nearly 1 per cent. of the roots, so that the amount of organic substance will be nearly 1 per cent. less than that of the total dry or solid matter. Further, there is, as a rule, the more mineral or saline matter, the more luxuriant, the more crude, and the more unripe the roots; and, so far, a relatively high percentage of mineral matter is indication of imperfect maturity and lower feeding value.

Next comes the percentage of nitrogen, the actual amount of which, in the fresh roots, is seen to be very small, but very variable. It is the lower the riper the roots, and it is conversely the higher the greater the luxuriance of growth, and less matured the roots. Indeed it is about one and a half time as high in the case of the largest as in that of the smallest crops; and it will presently be seen that where the amount is relatively high its condition is not so favourable for feeding purposes.

But it is to the lowest division of the Table to which I wish to direct special attention, namely, that showing the percentage of sugar in the roots. The figures show that the percentage of sugar is generally about two thirds that of the total dry or solid matter. In other words, nearly or about two thirds of the solid matter of the feeding Mangel is sugar. It is, indeed, a characteristic of the various descriptions of

TABLE XV.

MANGEL WURZEL.

Grown year after year on the same land, Barnfield, Rothamsted.

Results showing the effects of exhaustion and manures, on the percentage composition of the Roots.

Average of 4 years, 1877-'80.

	SERIES 1.	SERIES 2.	SERIES 3.	SERIES 4.	SERIES 5.
	No Nitrogenous Manure.	Sodium Nitrate = 86 lbs. Nitrogen.	Ammonium Salts = 86 lbs. Nitrogen.	Ammonium Salts and Rape Cake = 184 lbs. Nitrogen.	Rape Cake = 98 lbs. Nitrogen.

DRY MATTER.—PER CENT.

	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
1 Farmyard Manure ...	13·6	11·9	12·3	12·0	18·0
2 Ditto and Superphosphate ...	13·3	11·7	12·3	11·6	12·7
3 No Mineral Manure ...	16·9	18·6	15·6	13·8	14·9
5 Superphosphate ...	15·0	12·2	14·3	13·2	14·3
6 { Superphos. and Potassium Sulphate ...	15·2	12·3	13·9	13·0	13·5
4 { Superphos., Pot., and Mag- nesium Sulphates, and Sodium Chloride...	14·7	12·1	12·8	11·9	12·3
Mean of Plots 6 and 4...	15·0	12·2	13·4	12·5	12·9

MINERAL MATTER (ASH).—PER CENT.

1 Farmyard Manure ...	0·958	1·028	1·002	1·016	0·974
2 Ditto and Superphosphate ...	0·951	1·045	1·016	1·031	0·950
3 No Mineral Manure ...	0·818	0·952	0·820	0·796	0·799
5 Superphosphate ...	0·791	0·883	0·802	0·754	0·772
6 { Superphos. and Potassium Sulphates ...	0·912	0·975	0·990	0·988	0·908
4 { Superphos., Pot., and Mag- nesium Sulphates, and Sodium Chloride...	0·908	1·016	0·968	1·054	0·974
Mean of Plots 6 and 4...	0·908	0·996	0·979	1·021	0·989

NITROGEN.—PER CENT. (AVERAGE 3 YEARS ONLY, 1878-'80).

1 Farmyard Manure ...	0·157	0·200	0·190	0·213	0·180
2 Ditto and Superphosphate ...	0·168	0·196	0·192	0·208	0·188
3 No Mineral Manure ...	0·178	0·218	0·262	0·244	0·215
5 Superphosphate ...	0·134	0·180	0·182	0·219	0·188
6 { Superphos. and Potassium Sulphate ...	0·142	0·175	0·156	0·212	0·168
4 { Superphos., Pot., and Mag- nesium Sulphates, and Sodium Chloride...	0·121	0·160	0·132	0·168	0·143
Mean of Plots 6 and 4...	0·132	0·168	0·144	0·190	0·156

SUGAR.—PER CENT.

1 Farmyard Manure ...	8·6	7·1	7·7	7·1	7·8
2 Ditto and Superphosphate ...	8·6	6·9	7·3	7·1	7·8
3 No Mineral Manure ...	11·4	8·3	9·6	8·7	9·5
5 Superphosphate ...	10·4	7·5	9·3	8·0	9·4
6 { Superphos. and Potassium Sulphate ...	10·3	7·9	8·9	8·0	8·8
4 { Superphos., Pot., and Mag- nesium Sulphates, and Sodium Chloride...	10·1	7·4	8·5	7·1	8·0
Mean of Plots 6 and 4...	10·2	7·7	8·7	7·6	8·4

feeding roots that they supply a large amount of the non-nitrogenous, respiratory, and fat-forming substance—*sugar*.

They contain also other non-nitrogenous bodies, such as cellulose, and various pectin compounds, the feeding value of which is not yet satisfactorily determined ; but of the importance of the sugar there can be no question.

It is, therefore, obviously of much interest to consider the conditions under which its production is the most favoured. The point is strikingly illustrated in Table XVI., which shows the amounts of sugar yielded per acre under the different conditions as to manuring.

As to the effects of farm-yard manure, which is used so largely for the growth of the feeding beet or Mangel, it is seen that, taking the average of 4 years, considerably more than one ton of sugar per acre is produced by the farm-yard manure alone, and that the amount is increased to more than one and a half ton by the addition to the farm-yard manure of artificial nitrogenous manures.

The quantitative effect of the nitrogenous manures in increasing the amount of sugar produced is, however, more clearly seen in the results with the artificial manures. It must suffice to adduce in illustration the mean results obtained on the two mineral manured plots 6 and 4, of each series ; the mineral manure in these cases containing a full supply of potash. These results are given in the bottom line of figures in each of the two main divisions of the Table.

It is seen that there is an average of 1021 lbs. of sugar per acre in the roots of plots 6 and 4 of Series 1, that is without any nitrogenous manure, and that the amount is increased in the other series, where nitrogenous manures are also employed, to 2923, 2653, 3533, and 3063 lbs.

But the effects of the nitrogenous manures are still better discriminated in the figures in the lower main division of the Table, where are given the increased amounts of sugar yielded per acre on the plots with nitrogenous as well as mineral manure, over those on the corresponding plots with the mineral manures alone.

Thus, with 86 lbs. of nitrogen, applied as nitrate of soda, there is an average increase in the produce of sugar per acre on the two plots 6 and 4, of 1902 lbs. With 86 lbs. of nitrogen as ammonium-salts, there is an increase of 1632 lbs. With 98 lbs. as rape-cake, 2042 lbs. ; and with 184 lbs. nitrogen as rape-cake and ammonium-salts together, there is an increased production of sugar per acre in the roots of 2512 lbs.

There is obviously the more sugar produced the larger the amount of nitrogen applied as manure, but by no means in proportion to the amount applied. Then, again, the efficiency of a given supply of nitrogen is greatly dependent on the accompanying mineral supply, as is shown by the much less yield of sugar on plot 5, where, with superphosphate of lime annually applied without potash, the potash had become much exhausted.

The bottom line of the Table shows that, taking the mean of plots 6 and 4, each with potash, 1 lb. of nitrogen as nitrate of soda has

yielded 22.1 lbs. of sugar, 1 lb. as ammonium-salts 19.0 lbs. of sugar, 1 lb. of nitrogen in rape-cake 20.8 lbs.; and 1 lb. in rape-cake and ammonium-salts together 13.7 lbs. of sugar. In fact, the greater the excess of nitrogen supplied, the greater the luxuriance, and the less matured the roots, the less is the amount of sugar obtained for a given amount of nitrogen in the manure. It may be added that, with Sugar-beet, much more sugar was obtained for a given amount of nitrogen in manure, than with Mangels.

TABLE XVI.

MANGEL WURZEL.

Grown year after year on the same land, Barnfield, Rothamsted.

Results showing the effects of exhaustion and manures, on the amounts of sugar per acre in the roots.

Average of 4 years, 1877-'80.

		SERIES 1. No Artificial Nitrogenous Manure.	SERIES 2. Sodium Nitrate = 86 lbs. Nitrogen.	SERIES 3. Ammonium Salts = 86 lbs. Nitrogen.	SERIES 4. Ammonium Salts and Rape Cake = 184 lbs. Nitrogen.	SERIES 5. Rape Cake = 98 lbs. Nitrogen.
SUGAR PER ACRE, lbs.						
1	Farmyard Manure ..	2513	3109	3636	3700	3433
2	Farmyard Manure and Superphosphate..	2653	3272	3390	3357	3428
3	No Mineral Manure ..	950	2074	1428	1921	2044
5	Superphosphate ..	1028	2598	1808	2014	2306
6	Superphosphate and Potassium Sulphate	904.	2874	2567	3514	3023
4	Superphos., Pot., and Magnesium Sulphates, and Sodium Chloride	1137	2971	2739	3552	3103
	Means of 6 and 4 ..	1021	2923	2653	3533	3063

INCREASE OF SUGAR PER ACRE OVER SERIES 1, lbs.

1	Farmyard Manure ..		596	1123	1187	920
2	Farmyard Manure and Superphosphate..		619	737	704	775
3	No Mineral Manure ..		1124	478	971	1094
5	Superphosphate ..		1570	780	986	1278
6	Superphosphate and Potassium Sulphate		1970	1663	2610	2119
4	Superphos., Pot., and Magnesium Sulphates, and Sodium Chloride		1834	1602	2415	1966
	Means of 6 and 4 ..		1902	1632	2512	2042

lbs. INCREASE OF SUGAR FOR 1 lb. NITROGEN IN MANURE.

Means of 6 and 4 ..		22.1	19.0	13.7	20.8
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I cannot here discuss the physiological explanations of the fact that nitrogenous manures have such a marked effect on the production of the non-nitrogenous substance—sugar. A direct connection between the supply of nitrogen to the plant, and the formation of non-nitrogenous substances is, however, obvious. It is also obvious, that the effect of a given quantity of nitrogen may be very different, according to the character of the plant, to the mineral supply, and to the climatic conditions.

I will now briefly refer to the more detailed composition of some descriptions of roots, as illustrated by recently published experimental results of others.

Table XVII. gives a summary of results obtained by Dr. Aitken, and published in detail in the *Transactions of the Highland and Agricultural Society of Scotland*, Vol. xvi., 1884. They relate to the composition of Fosterton hybrid Turnips grown in 1882, at the Experimental Stations at Pumpherston and at Harelaw, under various conditions as to manuring. The figures show the mean results of the analyses of 60 differently grown specimens in each case.

TABLE XVII.
Mean of Dr. Aitken's results.

	Roots grown at Pumpherston.	Roots grown at Harelaw.
	Per cent.	Per cent.
Water	91.3	92.6
Dry Matter	8.7	7.4
Per cent. in Dry Matter:—		
Albumen	7.7	7.5
Woody Fibre	10.8	11.7
Ash	5.8	6.4
Carbohydrates, &c.	75.7	74.4
Total	100.0	100.0
AMOUNT AND CONDITION OF THE NITROGEN.		
Per cent. in Dry Matter:—		
As Albuminoids	1.22	
As Non-Albuminoids	0.23	
Total	1.45	
Per cent. of total as Albuminoids	84.1	
Albuminoid ratio	1 to 9.7	

It will be seen that the amount of dry matter averaged 8.7 per cent. in the roots grown at Pumpherston, and only 7.4 per cent. in those grown at Harelaw. It appears that the amount of sugar in the roots was not determined. The figures given in the Table for "carbohydrates, &c." are obtained by deducting the sum of the albumen, woody fibre, and ash, from 100. They include therefore any non-

albuminoid nitrogenous matters, and they are a fraction of 1 per cent. higher than the mean of the individual figures given by Dr. Aitken for "carbohydrates, &c.," by which he has calculated the albuminoid ratios, the average of which is given at the foot of the Table. The mean percentage of total nitrogen in the roots is very low, but the proportion of it which is estimated as albuminoid is unusually high.

Table XVIII. gives, in like manner, the mean results of 27 somewhat more detailed analyses of Aberdeen Yellow Turnips, made by Mr. David Wilson, jun. The roots were grown at Carbeth, Killearn, Stirlingshire, by a great variety of manures, and the results are published in the *Transactions of the Highland and Agricultural Society of Scotland*, Vol. xviii., 1886.

TABLE XVIII.
Mean of Mr. David Wilson's results.

	In Fresh Roots.	In Dry Matter.
	Per cent.	Per cent.
Water	91.09	
Sugar	4.72	52.94
Woody Fibre	1.03	11.64
Albuminoids	0.54	6.06
Non-Albuminoid Nitrogen $\times 6.25$	0.60	6.76
Extractive Matter free of Nitrogen	1.36	15.23
Ash	0.66	7.47
Total	100.00	100.00

AMOUNT AND CONDITION OF THE NITROGEN

Per cent. in Dry Matter :—						
As Albuminoids						0.970
As Non-Albuminoids						1.086
Total						2.056
Per cent. of total as Albuminoids.. .. .						47.3
Albuminoid ratio						1 to 12.4

The figures show that the roots contained on the average 91.09 per cent. of water, corresponding to 8.91 per cent. of dry matter. They also show that, of sugar there was an average of 4.72 per cent. in the fresh roots, corresponding to 52.94 per cent. of the total dry substance. The mean percentage of total nitrogen in the dry matter is much higher than in Dr. Aitken's experiments, namely, 2.056; of which only 47.3 per cent. existed as albuminoids. Further, the author reckons that the roots contained 1 part of albumen to 12.4 of "carbohydrates, &c." (including amides).

Table XIX. shows the detailed composition of common Turnips, the results being the mean of the analyses of eleven different specimens, including several different varieties, some grown in different seasons, or by different manures. The roots were grown in 1884 and 1885, on the farm of Canterbury College, New Zealand. The general results

are reported upon by Messrs. W. E. Ivey and G. Gray; and the analyses were made, and are reported upon, by Mr. Gray.

TABLE XIX.
Mean of Mr. G. Gray's results.

										In Fresh Roots.	In Dry Matter.
										Per cent.	Per cent.
Water	..	..	..	..	..	..	..	..	..	90.86	
Sugar	..	..	..	..	..	..	..	..	..	4.87	53.40
Fat, &c.	..	..	..	..	..	..	..	..	..	0.26	2.90
Cellulose	..	..	..	..	..	..	..	..	..	0.90	9.81
Albuminoids	..	..	..	..	..	..	..	..	..	0.37	4.01
Extractive Matters, including Amides, &c.	..	..	..	..	..	..	..	..	..	2.04	22.28
Ash	..	..	..	..	..	..	..	..	..	0.70	7.60
Total										100.00	100.00

AMOUNT AND CONDITION OF THE NITROGEN.

Per cent. in Dry Matter :—											
As Albuminoids	..	..	..	..	..	..	..	..	..		0.632
„ Ammonia Salts	..	..	..	..	..	..	..	..	..		0.018
„ Nitrates	..	..	..	..	..	..	..	..	..		0.013
„ Amides, &c.	..	..	..	..	..	..	..	..	..		0.680
Total											1.343
Per cent. of Total Nitrogen :—											
As Albuminoids	..	..	..	..	..	..	..	..	..		47.64
„ Ammonia Salts	..	..	..	..	..	..	..	..	..		1.37
„ Nitrates	..	..	..	..	..	..	..	..	..		0.89
„ Amides, &c.	..	..	..	..	..	..	..	..	..		50.10
Total											100.00
Albuminoid Ratio											1 to 21

It may of course be a question whether the roots would not mature somewhat better, or at any rate differently, in the climate of New Zealand than in our own; but the results are nevertheless of interest, both in themselves, and for comparison with those obtained by others, in other localities.

The figures show that the average percentage of dry matter was a little over 9, and that the average percentage of sugar was 4.87, corresponding to 53.4 per cent. of the total dry substance of the roots. Some other of the results will be referred to presently.

The next point to consider is the amount, and the condition, of the nitrogen in Roots of different descriptions, or grown under different conditions.

In perfectly ripened seeds, by far the larger proportion of the nitrogen exists as albuminoids; in fact, in many cases nearly the whole of the nitrogen is in that form. In ripened products, however, some, and in unripened ones sometimes a large proportion, of the nitrogen

exists as amides. Now, so far as present knowledge goes, it is only the nitrogen existing in food as albuminoid compounds, that can contribute to the formation of the nitrogenous compounds of animal bodies, or of milk. It would seem not improbable, however, that some amide compounds may replace the albuminoids in supplying material for the transformations incident to the constant waste of the nitrogenous substances of the body, the products of which pass from it in the urine.

Then, again, besides albuminoids and amides, succulent or immature vegetable substances may contain nitrogen as nitric acid, or as ammonia, unchanged from the condition in which it has been taken up by the roots of the plant from the soil, or the one transformed into the other.

The question as to the condition of the nitrogen in vegetable food, and especially in such crude and immature products as our feeding roots, is, therefore, one of great importance to consider. In the early reports of Rothamsted feeding experiments, published from 35 to 40 years ago, we called attention to the fallacy of estimating the whole of the nitrogen of our stock-foods as protein or albuminoid compounds, especially in the case of succulent and unripened products.

Table XX. gives results as to the condition of the nitrogen, in the experimental rotation Swedes grown at Rothamsted in 1880, and in the experimental Mangels, grown in 1878, 1879, and 1880.

It will be remembered that one portion of the rotation land had been entirely unmanured throughout 10 courses of four years each, and that the roots so grown were quite abnormal; none of the characters of the cultivated root being developed under these circumstances. The results given in the Table (XX.) relate to the roots grown in 1880, which constituted the first crop of the ninth course. It is seen that with a very high percentage of total nitrogen in the roots (0.347 in the fresh, and 2.758 in the dry), they also contained a high percentage of albuminoid nitrogen, which corresponded, however, to only 32.9 per cent. of the total nitrogen.

The next plot has, through the same 10 courses, received no nitrogenous manure whatever. For each of the first nine courses it received superphosphate of lime alone, but for the tenth course, salts of potash, soda, and magnesia, in addition. Under these conditions the roots of the ninth course show a very low percentage of nitrogen in their dry substance (0.888), but 55.8 per cent. of it existed as albuminoid compounds.

Lastly, the third plot received, each course, a complex manure, both mineral and nitrogenous. The percentage of total nitrogen in the dry substance of the roots (1.539), though not high, was nevertheless nearly twice as high as in the case of the roots grown by superphosphate alone; and the proportion of the nitrogen which was as albuminoids, was only 40.1 per cent.

Then again, it is seen that in the cultivated roots by far the larger proportion of the albuminoid nitrogen existed in the juice, that is to say was soluble; whilst in the unmanured or, so to speak, uncultivated roots, a comparatively small proportion of the total albuminoids existed in the juice.

TABLE XX.
Showing the condition of the Nitrogen in Swedish Turnips, and in Mangel Wurzel.

Per cent. of the Total Nitrogen.											
	Total Nitrogen.			Albuminoid Nitrogen.			As Albuminoids.				
	In fresh Roots.	In dry matter.	In fresh Roots.	In dry matter.	In Marc.	In Juice.	Total.		As Amides.	As Nitric Acid.	Total.
							In	In			
ROTATION SWEDES. SEASON 1880.											
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Unmanured ..	0.347	2.758	0.114	0.906	21.1	11.8	32.9	?	?	?	100
Superphosphate ..	0.108	0.888	0.060	0.495	20.4	35.4	55.8	?	?	?	100
Mixed Manure ..	0.171	1.539	0.066	0.595	14.6	25.5	40.1	?	?	?	100
MANGEL WURZEL. 1878. (Mineral Manures and Rape Cake.)											
Superphosphate ..	0.211	1.590	0.065	0.590	7.6	23.0	30.6	?	?	?	69.4
Superphosphate and Potassium Sulphate ..	0.197	1.618	0.057	0.578	10.7	18.3	29.0	?	?	?	100
Superphos., Pot., and Magnesium Sulphates, and Sodium Chloride ..	0.171	1.525	0.035	0.390	1.8(*)	18.7	20.5	?	?	?	100
MANGEL WURZEL. 1879. (Mineral Manures and Rape Cake.)											
Superphosphate ..	0.182	1.166	0.071	0.563	17.0	21.7	38.7	?	?	4.2	100
Superphosphate and Potassium Sulphate ..	0.157	1.087	0.065	0.560	19.1	22.1	41.2	?	?	11.1	100
Superphos., Pot., and Magnesium Sulphates, and Sodium Chloride ..	0.136	1.010	0.055	0.506	15.3	24.8	40.1	?	?	14.2	100
MANGEL WURZEL. 1880. (Mineral Manures and Rape Cake.)											
Superphosphate ..	0.165	1.344	0.059	0.613	13.4	22.7	36.1	?	?	12.0	100
Superphosphate and Potassium Sulphate ..	0.151	1.145	0.067	0.628	18.5	25.7	44.2	?	?	?	100
Superphos., Pot., and Magnesium Sulphates, and Sodium Chloride ..	0.123	1.099	0.051	0.564	16.3	25.0	41.3	?	?	11.7	100

(*) Probably too low.

These results with Swedish Turnips are very instructive, as showing how very dependent is the proportion of the nitrogen existing in the favourable food condition of albuminoid compounds, on the conditions of the manuring, and on the maturity of the crop.

In the results relating to the Mangels the influence of season as well as of manure, on the condition of the nitrogen, is illustrated.

Three plots were selected for investigation, which, with pretty full amounts of produce, would give roots of fairly good degree of maturation, namely, those manured with rape-cake in addition to various mineral manures.

In 1878 there were somewhat under-average crops, with a large proportion of leaf, conditions indicative of comparative immaturity. Under these circumstances, the percentage of total nitrogen in the roots was not high, but the proportion of the total nitrogen existing as albuminoids was low, namely 30·6 and 29·0 per cent. in two cases, and only 20·5 per cent. in the third, but in this last case it was concluded that the determination was too low.

In the very wet and cold season of 1879 the crops were very small, and the percentage of total nitrogen was low, the result being, doubtless, partly due to loss of nitrogen by drainage. Under these circumstances the amounts of the total nitrogen found as albuminoids were 38·7, 41·2, and 40·1 per cent., or an average of about 40 per cent.

In 1880 the crops were much above the average, and the percentage of total nitrogen was low; and there is again, under the better conditions as to mineral manuring, that is where potash was applied, more than 40 per cent. of the total nitrogen albuminoid.

As in the case of the manured Swedes, so in every case with the Mangels, the greater part of the albuminoid nitrogen is in the juice, that is to say it is soluble.

The bottom division of the Table shows that in the crops of 1880, in which alone the amides were determined, the proportion of the nitrogen in that condition was, in each case, somewhat over 40 per cent. of the total nitrogen, or approximately the same as that of the albuminoid nitrogen. Table XIX. (p. 38), which gives the average composition of the eleven New Zealand specimens of common Turnips, shows that the proportion of the nitrogen reckoned as "amides, &c.," was 50·1 per cent. of the total nitrogen; that is, rather more than was found as albuminoids in the same roots, and more than was found as amides in the Rothamsted Mangels.

In all three cases in 1879, and in two in 1880, the amount of the nitrogen existing as nitric acid was also determined. It is seen that, with one exception, in which the nitrogen as nitric acid amounted to only 4·2 per cent. of the total nitrogen, it ranged from 11 to 14 per cent. of the total. Compared with these amounts, the results given in Table XIX. show less than 1 per cent. of the total nitrogen of the common turnips to exist as nitric acid, and not much more than 1 per cent. as ammonia. It may be added that in some determinations made at Rothamsted in Swedes, the proportion of the total nitrogen as nitric acid was very much less than in the Mangels.

The results of Dr. Aitken, with Fosterton Hybrid Turnips, show in no case less than 70, in several over 90, and an average of 84.1 per cent. of the total nitrogen as albuminoids; that is about twice as much as was, in most cases, found at Rothamsted in Swedish Turnips and Mangel Wurzel. The results of Mr. David Wilson, with Aberdeen Yellow Turnips, show a range from 32.0 to 62.9, and an average of 47.3 per cent. of the total nitrogen to be albuminoid. Lastly, those of Mr. G. Gray, with the eleven different specimens of common Turnips grown in New Zealand, show a range from 29.94 to 61.01, and an average of 47.64 of the total nitrogen to be albuminoid.

Thus the results obtained with common Turnips by Mr. David Wilson and by Mr. G. Gray, agree in showing an average of less than 50 per cent. of the total nitrogen to exist as albuminoids; and their results are, so far, fairly accordant with those obtained at Rothamsted with Swedes. The results of Dr. Aitken, on the other hand, show, with Fosterton Hybrid Turnips, grown at Pumpherston, an average of 84 per cent. of the total nitrogen to be albuminoid. It is, indeed, well known that Turnips grown in certain localities on the East of Scotland have, weight for weight, a much higher feeding value than those grown in the West of Scotland, or in England. But it is certainly very remarkable that any such products as succulent Roots should contain as high a proportion of their total nitrogen in the albuminoid condition as might be found in imperfectly ripened grain.

If the result be real, and neither it nor the season were exceptional, the question suggests itself whether the quality of feeding roots may not be improved in this direction, as well as in that of increased yield of sugar, by the careful selection of plants from which to grow seed, as has been done with such marvellous success in the case of Sugar-beet with a view to an increased production of sugar. At the same time, the results which have been adduced afford abundant evidence that roots grown from the same seed will vary very greatly, both as to their percentage of sugar, and as to the amount and the condition of their nitrogen, according to the conditions of growth, and to the maturity of the crop.

SUMMARY AS TO THE COMPOSITION, AND THE FEEDING QUALITIES, OF ROOTS.

So far as the evidence at command enables us to judge, there is in Mangels, with their more extended root-range, greater power of accumulation, more luxuriant growth, and frequent greater immaturity when taken up, a somewhat less proportion of the total nitrogen in the albuminoid condition than in either common Turnips or Swedes. There is also, probably, a less proportion of amide nitrogen, and pretty certainly a larger proportion of nitrogen as nitric acid, and in other forms.

It has been shown that root-crops, as grown for stock-food, are essentially *sugar crops*.

The results obtained by Mr. David Wilson, with Aberdeen Yellow

Turnips, show an average of 8.91 per cent. of dry matter, and of 4.72 per cent. of sugar, in the fresh roots, corresponding to 52.94 per cent. of sugar in the dry substance of the roots.

The eleven specimens of Turnips, grown in New Zealand, show an average of 9.14 per cent. of dry matter, and 4.87 per cent. of sugar, in the fresh roots, corresponding to 53.4 per cent. of sugar in the dry matter.

In Johnston's *Elements of Agricultural Chemistry and Geology*, by Cameron, the following estimates of the average percentages of dry matter, and of sugar, in various descriptions of roots, are given :—

	White Turnips.	Yellow Turnips.	Swedish Turnips.	Mangel Wurzel.
	Per cent.	Per cent.	Per cent.	Per cent.
Dry Matter ..	8.00	9.44	10.54	12.00
Sugar ..	3.00	3.90	4.60	5.60

These percentages of sugar in the fresh roots correspond, respectively, to 37.5, 41.3, 43.6, and 46.7 per cent. in the dry substance.

In a lecture delivered in February, 1886, before the Kingscote Agricultural Association, Dr. Voelcker gives the following estimates of the average amounts of dry matter, and of sugar, in various roots :—

	Turnips.	Swedes.	Mangels.
	Per cent.	Per cent.	Per cent.
Dry Matter	8.5	10.5	11.5
Sugar	3.0	5.0	5.5

These amounts of sugar in the fresh roots correspond to 35.3 per cent. in the dry substance of the turnips, to 47.6 per cent. in that of the swedes, and to 47.8 per cent. in that of the mangels.

The amounts of sugar found in the experimental rotation Swedes grown at Rothamsted in 1880 were :—

	In fresh Roots.	In Dry Matter.
	Per cent.	Per cent.
Without Manure	6.26	49.75
With Superphosphate	7.69	63.42
With Mixed Manure, including Nitrogen	6.30	56.77

Table XV. (p. 33) shows that in Mangels grown with rape-cake and mineral manures, the average percentage of sugar over four years, ranged, according to the mineral manure, from 8.0 to 9.4 per cent. in the fresh roots, corresponding (with different percentages of dry matter in the two cases) to 65.0 and 65.7 per cent. in the dry substance.

The various results adduced clearly show, not only that the various descriptions of Roots differ much in composition one from another, but that the composition of one and the same description will vary very greatly, according to the conditions of growth, and of the maturity of

the Roots accordingly. It will nevertheless be useful to give such an estimate as the evidence at command permits, of the approximate average percentages of dry matter, and of sugar, in different descriptions of feeding roots.

TABLE XXI.

Estimates of the approximate average percentages of dry matter, and of sugar, in different descriptions of roots.

	Dry Matter	Sugar per cent.	
		In Fresh Roots.	In Dry Matter.
White Turnips	Per cent. 8.0	Per cent. 3.5 to 4.5	Per cent. 44 to 56
Yellow Turnips	9.0	4.0 to 5.0	44 to 56
Swedish Turnips	11.0	6.0 to 7.0	55 to 64
Mangel Wurzel	12.5	7.5 to 8.5	60 to 68

Thus, then, even in common Turnips, one half or more of the total solid matter of the roots may be sugar. Of the total dry matter of Swedish Turnips a larger proportion, and of that of Mangels a larger proportion still, will be sugar; indeed, in well-matured Mangels, about two-thirds of the total solid matter may be sugar.

Now, it may be stated that, in the cereal grains, the proportion of albuminoid matter to the non-nitrogenous food material (starch, &c.) is about as 1 to 6 (more or less); and that this is a proportion which may be said to be as a rule fairly favourable for the requirements of fattening animals.

According to the results and calculations of Dr. Aitken, the albuminoid ratio, that is the ratio of the "carbohydrates, &c." to 1 of albumen, ranged from 7.6 to 12.2, and averaged about 10, in the sixty specimens of Fosterton Hybrid Turnips grown at Pumpherston. Mr. David Wilson's results, with Aberdeen Yellow Turnips, show a range from 6.5 to 16.4, and an average of 12.4 "carbohydrates, &c." (including amides, &c.) to 1 of albumen. According to the calculations of Mr. G. Gray, in the eleven specimens of common Turnips grown in New Zealand, the albuminoid ratio ranged from 1 to 16 to 1 to 31; and it averaged about 1 to 21. It would appear that, in none of these various estimates is any of the woody fibre estimated as digestible, though it is probable that some of it would be so when consumed by ruminants. On the other hand, in the calculations of Mr. David Wilson and Mr. G. Gray, the non-albuminoid nitrogenous compounds are included with the carbohydrates, &c.; but Dr. Aitken's figures do not clearly show whether or not he has so included them.

The estimates are, therefore, obviously only approximations to the truth; but the results are nevertheless of much significance and importance, in showing how comparatively very low is the proportion of albuminoid to digestible non-nitrogenous matter in common Turnips. In the case of other roots, such as Swedish Turnips and Mangels, it is probable that, owing to the greater proportion of sugar which they

contain, the ratio of the albuminoid to the non-nitrogenous matters will, as a rule, be lower still.

It is obviously very essential to give with Roots other foods which are richer in albuminoid substances, and which contain a higher proportion of albuminoid to digestible non-nitrogenous substances. Nevertheless, Roots are, by virtue of the amount of sugar they supply, very valuable for meeting the respiratory requirements of the animals, and also for fat-forming, and for milk production, when given in due admixture.

In conclusion, from all the illustrations that have been adduced, it will be obvious that both the quantity and quality of the produce, and consequently its feeding value, will greatly depend on the selection of the best description of Roots to be grown, and on the character and the amount of the manure, and especially on the amount of nitrogenous manure, to be employed. It will at the same time be obvious, that no hard and fast lines can be laid down in regard to these points. Independently of the necessary consideration of the general economy of the farm, the choice must be influenced partly by the character of the soil, but very much more by that of the climate. Judgment, founded it is true on knowledge, and aided by careful observation, both in the field and in the feeding shed, must be relied upon as the guide of the practical farmer.

GENERAL SUMMARY, AND CONCLUSIONS.

1. Like Sugar-beet grown for sugar, Roots grown for feeding purposes, are very artificial productions. The swollen root consists of a very abnormal development of the reserve material for the second growth of stem and seed; and the conditions of growth, as to the period of the season selected, the soil, and the manuring, are such as to obtain the maximum development within the season.

2. Roots, as grown in our rotations, are generally considered to be restorative crops. But they depend for their successful development on large quantities of manure; which is sometimes applied for the previous grain crop, but more frequently directly for the Roots themselves; and when grown without manure, even, from the same seed as the manured crop, either for a few years in succession on the same land, or even in rotation, they soon revert to the uncultivated condition.

3. Independently of the great advantage arising from the opportunity which the growth of Roots affords for the cleaning of the land, the benefits of growing the crop in rotation are due—to the large amount of manure applied for its growth, to the large residue of the manure left in the soil for future crops, to the large amount of matter at once returned as manure again in the leaves, to the large amount of food produced, and to the small amount of the most important manurial constituents of the roots which is retained by the animals consuming them, the rest returning as manure again.

4. It is entirely fallacious to suppose that Root-crops gain a large amount of nitrogen from atmospheric sources by means of their extended leaf-surface. No crop is more dependent on nitrogen in an available condition within the soil; and if a good crop of Turnips is grown by superphosphate of lime alone, it is a proof that the soil contained the necessary nitrogen. In fact, provided the season be favourable, the *condition* of land, so far as nitrogen is concerned, may be more rapidly exhausted by the growth of Turnips by superphosphate than by any other crop.

5. A characteristic difference between the uncultivated and the cultivated Turnip root is, that the cultivated root contains a much lower percentage of nitrogen, and a much higher percentage of non-nitrogenous constituents, especially sugar, by the accumulation of which the percentage of nitrogen is reduced. Yet it is under the influence of nitrogenous manures that the greatest amount of the non-nitrogenous substance—sugar—is produced.

6. If nitrogenous manures are used in excess, that is in such amount as so to force luxuriance that the roots do not properly mature within the season, there will be, not only a restricted production of root, but an undue amount and proportion of leaf. In fact, the higher the nitrogenous manuring, and the heavier the soil, the greater is the tendency to produce a large amount of leaf.

7. In the case of both common and Swedish Turnips, the leaf contains a much higher percentage of dry substance than the root; and the dry substance of the leaf contains a much higher percentage of both nitrogen and total mineral matter than does that of the root.

8. Common Turnips yield a much higher proportion of leaf to root than Swedish Turnips; and if the leaf be unduly developed, there may even be more nitrogen, and more total mineral matter, remaining in the leaf to serve only as manure again, than accumulated in the root to be used as food. In the case of Swedish Turnips, however, not only is the proportion of leaf to root very much less under equal conditions of growth, but the amount of dry matter, of nitrogen, and of mineral matter, remaining in the leaf, is very much less than in the root. In fact, whilst in the case of common Turnips a very large amount of the matter grown is accumulated in the leaf and only serves as manure again, in that of Swedish Turnips a comparatively small proportion of the produce is useless as food for stock.

9. The root of the Swedish Turnip contains a less percentage of water, that is a higher percentage of solid matter or food-material, than that of the common Turnip. The dry or solid matter of the Swedish Turnip root also contains a lower percentage of mineral matter, and consequently a higher proportion of organic food-substance.

10. The more deeply and powerfully rooting, and more vigorous Mangel, is sown earlier, has a longer cycle of growth, and even under the same conditions as to manuring, yields more produce per acre than

either common or Swedish Turnips. It requires, however, for full crops, much heavier dressings of manure.

11. The proportion of Mangel leaf to root is, as a rule, very much less than in the case of common Turnips, but more than in that of Swedish Turnips.

12. With the more extended root range of the Mangel, it is less dependent on continuity of rain when growth is once well established; and it bears, or rather requires, for its full development, a higher temperature than the Turnip.

13. The Mangel root contains a higher percentage of solid matter than either common or Swedish Turnips. But whilst the Turnip leaf contains a much higher percentage of dry matter than the Turnip root, the Mangel leaf contains a much lower percentage of dry matter than the Mangel root; and also a very much lower percentage than the Turnip leaf.

14. As in the case of Turnips, the dry substance of the Mangel leaf contains a much higher percentage of both nitrogen and mineral matter than does the dry substance of the root. Indeed the dry substance of the Mangel leaf contains not far from twice as high a percentage of mineral matter as that of the Turnip leaf; but it contains upon the whole a rather lower percentage of nitrogen than that of the Turnip leaf. It would seem that the Mangel leaf is more fully exhausted of migratory organic matters in the greater development of the root, than is the Swede leaf, and more still than the common Turnip leaf.

15. Superphosphate is much less beneficial to Mangels than to Turnips. In mangels, as in Turnips, the amount of dry substance grown has a very direct relation to the amount of nitrogen available within the soil. But more vegetable substance was produced, and more stock-food yielded, from a given quantity of nitrogen applied to Mangels, than to either description of Turnips. By the application of nitrogen to the soil for Mangels, there was, in many cases, an increased assimilation of about a ton of carbon per acre from the atmosphere.

16. Taking the average of six years, the amount of nitrogen recovered in the increased crop of Mangel roots was about 60 per cent. of that supplied when nitrate of soda was used, about 42 per cent. when ammonium-salts, about 50 per cent. when rape cake, and about 46 per cent. when an excessive amount in a mixture of rape cake and ammonium-salts was employed. There was, of course, an additional amount accumulated in the leaves, but these were annually returned to the soil as manure.

17. When farmyard manure is applied for Mangels, larger amounts of nitrogen are supplied per acre than were used in any of the Rothamsted experiments with artificial manures, a less proportion of the nitrogen supplied is recovered in the increase of crop, and more remains for

future crops. It is the nitrogen of the liquid dejections of the animals that is first rendered available within the soil, then that of the finely comminuted matter mixed with some secretions in the solid excrements, and finally that of the litter.

18. As in the case of Turnips, these assumed restorative crops are themselves pre-eminently dependent on manure for their development. They produce a large amount of vegetable substance, but a large amount of the manure remains for future crops; whilst, of the substance grown, that accumulated in the leaf is at once manure again, and of the portion used as food by far the larger proportion of the constituents valuable as manure is eventually recovered as such in the excrements of the animals. When, however, the roots are consumed for the production of milk, the loss to the manure will be greater than when they are consumed by either store or fattening stock.

19. The selection of the proper description of Roots to be grown cannot be settled merely by a consideration of the amount of produce obtained from a given quantity of manure, of the proportion of the crop which is available as food for stock or only remains for manure again, or of the high or low percentage of solid matter in the food portion of the crop. The general economy of the farm, the character of the soil, but more especially that of the climate of the locality, must also be taken into account. The great influence of climate is strikingly illustrated by the different proportions in which the different descriptions of Roots are grown in different divisions of the United Kingdom.

20. The experiments showed a higher percentage of dry matter in Swedish than in common Turnips, and a higher percentage in Mangels than in Swedes. But, with each description of Roots, the range in the percentage was considerable, according to season and to manuring. The percentage of dry matter was the lower, the greater the excess of nitrogenous manure, the greater the luxuriance, the larger the crops, and the less matured the roots; and it was, conversely, the higher the more matured the Roots.

21. The percentage of mineral matter in the Roots was the higher, the greater the luxuriance, and the more crude and unripe the Roots.

22. The percentage of nitrogen in the Roots was very small, but very variable. It was the higher the more nitrogen was applied by manure, the greater the luxuriance, and the less matured the Roots; and it was the lower the riper the Roots.

23. Nearly two-thirds of the dry substance of Mangels was found to be sugar. The *percentage* of sugar was the greater the more mature the Roots; and it was consequently the greater in the Roots of the smaller crops. But the amount of sugar *per acre* was much the greatest with the largest crops; that is where the most nitrogen was applied in the manure. The Roots grown by farmyard manure alone contained more than one ton of sugar per acre; and by the addition of artificial nitrogenous manure to the farmyard manure, there was an

increase of more than half a ton of sugar per acre. In several cases the addition of artificial nitrogenous to a complete mineral manure, increased the production of sugar by more than a ton per acre.

24. By the addition of nitrogenous to a complete mineral manure, 1 lb. of nitrogen applied as nitrate of soda yielded an increase of 22.1 lbs. of sugar; 1 lb. nitrogen as ammonium-salts 19 lbs. of sugar; 1 lb. as rape cake 20.8 lbs. of sugar; and 1 lb. of nitrogen applied in excessive amount in a mixture of rape cake and ammonium-salts gave an increase of only 13.7 lbs. of sugar.

25. In ripened products by far the larger proportion of the nitrogen exists in the most favourable food-condition of albuminoids, or protein compounds; but in unripened ones, and especially in such succulent, crude, and immature productions, as feeding roots, a large portion of the nitrogen exists in the much less valuable condition of amide-compounds, and in some cases a not inconsiderable amount is in the non-food, or even injurious forms, of nitrates and ammonium salts.

26. In Mangels, with their more luxuriant growth, and frequent greater immaturity when taken up, there is probably, as a rule, a less proportion of the total nitrogen in the albuminoid condition than in either common Turnips or Swedes. There is also probably a less proportion of amide nitrogen, and pretty certainly a larger proportion of nitrogen as nitrates and in other forms. But the range in the proportion of the nitrogen as albuminoids varies very much with each description of roots, being the less the greater the luxuriance, and the less matured the crop.

27. Feeding roots are essentially *sugar crops*. Although the percentage of dry matter varies considerably with each description of Root, according to the conditions of growth, the average amount of dry matter may be taken as, approximately, 8 per cent. in white Turnips, 9 per cent. in yellow Turnips, 11 per cent. in Swedes, and 12.5 per cent. in Mangels. Of the dry matter of white and yellow Turnips nearly, or more than half, may be sugar; of that of Swedes more than half; and of that of Mangels nearly, or as much as, two-thirds may be sugar.

28. In cereal grains, the proportion of albuminoid matter to non-nitrogenous food-material is about as 1 to 6. In roots the albuminoid ratio varies very greatly; but it is probably seldom more than 1 to 12, and frequently as low as 1 to 20 or more. The ratio will probably, as a rule, be lower in Swedes than in common Turnips, and lower still in Mangels.

29. With Roots, should be given other foods, richer in albuminoid matters, and which contain a higher proportion of albuminoid to digestible non-nitrogenous substances; but they are, by virtue of the large amount of sugar they supply, very valuable for meeting the respiratory requirements of the animals, also for fat-forming, and for milk-production.

30. Both the quantity and the quality of feeding Roots, and consequently the feeding value of the crop, depend greatly on the description grown, and on the character and amount of the manure, and especially on the amount of nitrogenous manure, employed. Independently of the necessary consideration of the general economy of the farm, the choice on these points must be guided, partly by the character of the soil, but very much more by that of the climate of the locality.

RESULTS OF EXPERIMENTS AT ROTHAMSTED,
ON THE
GROWTH OF POTATOES,

FOR TWELVE YEARS IN SUCCESSION
ON THE SAME LAND;

BEING

A LECTURE DELIVERED JULY 27, 1888,

AT THE

ROYAL AGRICULTURAL COLLEGE,
CIRENCESTER,

BY

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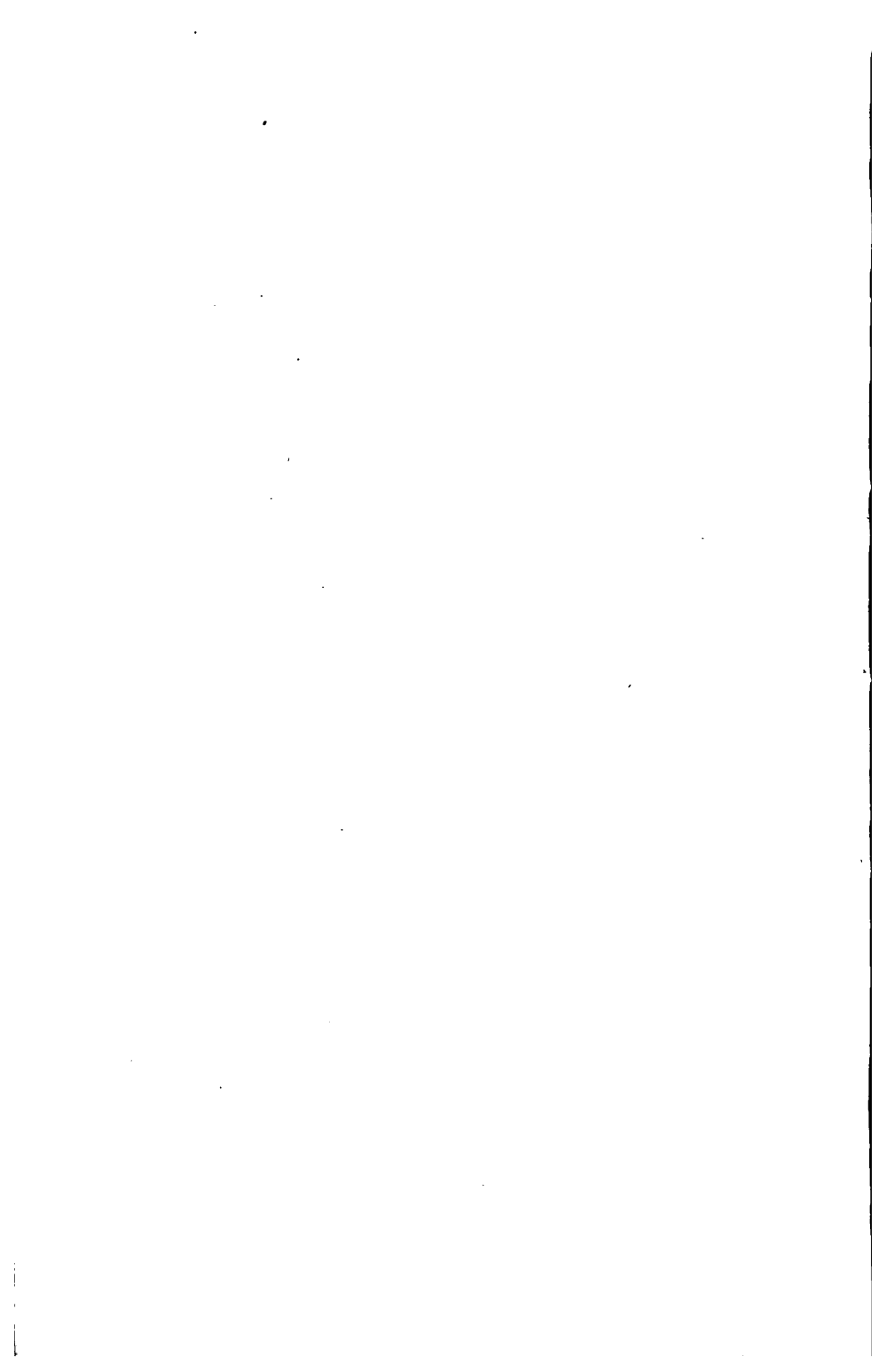
SIBTHORPIAN PROFESSOR OF RURAL ECONOMY
IN THE UNIVERSITY OF OXFORD,

AND

HONORARY PROFESSOR OF THE COLLEGE.



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INTRODUCTION.

My lecture here last year was devoted to the consideration of the conditions and the results of growth of the pre-eminently sugar-yielding root-crops, and I have now to direct your attention to the conditions and the results of growth of the pre-eminently starch-yielding Potato.

From the point of view of the vegetable physiologist the Potato is not a root, but a tuber; but from the point of view of the agriculturist it might well be classed as a root-crop.

It does not fall within my scheme of illustration, to discuss at any length the history of the Potato as a European crop. It will suffice to say that it seems to have been introduced into this country from Virginia, just about three centuries ago; though it is probable that it had been introduced into Portugal, and thence into other continental countries, some years earlier.

It is also outside of my plan to enter into a consideration of the comparative characters of the enormous number of varieties now cultivated; or of the differences in the treatment of the crop, according to soil, climate, and other local circumstances.

My special object is to show the general requirements of the crop, both actually, and as compared with other crops, and the actual and comparative characters and composition of the product obtained.

As in my lectures on other crops, I propose to draw my illustrations, mainly from the results of Field experiments on the growth of the Potato by different manures, for a number of years in succession on the same land, at Rothamsted, and from those of collateral investigations into the composition of the produce, made in the Rothamsted Laboratory. I shall, however, bring to my aid the results of other investigators, so far as the subject may require, and my limits as to time and space will permit.

PRODUCE WITHOUT MANURE, AND WITH VARIOUS ARTIFICIAL MANURES.

First as to the average produce of Potatoes, per acre, per annum, without manure, and with different descriptions of manure.

Table I. (p. 3), shows the results obtained without manure, and by six different descriptions of artificial manure; and Table II. (p. 7), shows the results without manure, and with farm-yard manure, either alone, or with other manures.

In each case, the particulars given are, the average annual amounts obtained per acre, of good, of small, and of diseased Potatoes, the total amount of tubers, and the percentage of diseased in the total produce. In the case of the artificial manure series, these particulars are given, for the first four, the second four, the third four, and the total period of twelve years, of the continuous growth of the crop on the same land; and in the case of the farm-yard manure series, the results are given for six, six, and twelve years.

The artificial manure series comprises the following conditions as to manuring:—

1. Without manure.
2. Superphosphate of lime alone.
3. A "mixed mineral manure," containing superphosphate, and salts of potash, soda, and magnesia.
4. Ammonium-salts alone, supplying 86 lbs. of nitrogen, per acre per annum.
5. Nitrate of soda alone, also supplying 86 lbs. of nitrogen, per acre per annum.
6. The ammonium-salts, and the "mixed mineral manure" together.
7. The nitrate of soda, and the "mixed mineral manure" together.

It should be added, that the description of Potatoes grown during the first four years was the "Rock," but subsequently the "Champion."

The last column but one of Table I. shows that, without manure, with ammonium salts alone, and with nitrate of soda alone, the average produce of tubers was less over each succeeding period of four years. On the other hand, with the superphosphate alone, with the mixed

TABLE I.
POTATOES.*Grown year after year on the same land, Hoosfield, Rothamsted.*

Manures and Produce per acre per annum; 12 years, 1876-1887.

		Good,	Small.	Diseased.	Total.	Per cent. Diseased in Total.
UNMANURED. (Plot 1.)						
Averages		Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Per cent.
	4 years, 1876-1879	2 3 $\frac{3}{4}$	0 6 $\frac{1}{2}$	0 2 $\frac{1}{2}$	2 12 $\frac{1}{2}$	5.14
	4 years, 1880-1883	1 12 $\frac{1}{2}$	0 4 $\frac{1}{2}$	0 0 $\frac{1}{2}$	1 18 $\frac{1}{2}$	1.63
	4 years, 1884-1887	1 3 $\frac{3}{8}$	0 4	0 0 $\frac{1}{2}$	1 8	1.43
	12 years, 1876-1887	1 13 $\frac{1}{2}$	0 5	0 1 $\frac{1}{2}$	1 19 $\frac{1}{2}$	3.15
SUPERPHOSPHATE OF LIME. (Plot 9.)						
Averages		Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Per cent.
	4 years, 1876-1879	2 18 $\frac{1}{2}$	0 8 $\frac{1}{2}$	0 4 $\frac{1}{2}$	3 11 $\frac{1}{2}$	6.89
	4 years, 1880-1883	4 9 $\frac{1}{2}$	0 5	0 2 $\frac{1}{2}$	4 16 $\frac{1}{2}$	2.16
	4 years, 1884-1887	2 7 $\frac{1}{2}$	0 3 $\frac{1}{2}$	0 1	2 11 $\frac{1}{2}$	1.98
	12 years, 1876-1887	3 5	0 5 $\frac{1}{2}$	0 2 $\frac{1}{2}$	3 13 $\frac{1}{2}$	3.66
MIXED MINERAL MANURE. (Plot 10.)						
Averages		Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Per cent.
	4 years, 1876-1879	3 3 $\frac{3}{4}$	0 6 $\frac{1}{2}$	0 5 $\frac{1}{2}$	3 15 $\frac{1}{2}$	6.90
	4 years, 1880-1883	4 9 $\frac{1}{2}$	0 4 $\frac{1}{2}$	0 1 $\frac{1}{2}$	4 16	1.64
	4 years, 1884-1887	2 9 $\frac{1}{2}$	0 3 $\frac{1}{2}$	0 1	2 14 $\frac{1}{2}$	1.87
	12 years, 1876-1887	3 7 $\frac{1}{4}$	0 4 $\frac{1}{2}$	0 2 $\frac{1}{2}$	3 15 $\frac{1}{2}$	3.45
AMMONIUM SALTS = 86 lbs. NITROGEN. (Plot 5.)						
Averages		Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Per cent.
	4 years, 1876-1879	2 7 $\frac{1}{2}$	0 6 $\frac{1}{2}$	0 4 $\frac{1}{2}$	2 18 $\frac{1}{2}$	7.45
	4 years, 1880-1883	1 16 $\frac{1}{2}$	0 6 $\frac{1}{2}$	0 0 $\frac{1}{2}$	2 3 $\frac{1}{2}$	1.76
	4 years, 1884-1887	1 9 $\frac{1}{2}$	0 5 $\frac{1}{2}$	0 0 $\frac{1}{2}$	1 15 $\frac{1}{2}$	1.36
	12 years, 1876-1887	1 17 $\frac{1}{2}$	0 6 $\frac{1}{2}$	0 1 $\frac{1}{2}$	2 5 $\frac{1}{2}$	4.06
NITRATE OF SODA = 86 lbs. NITROGEN. (Plot 6.)						
Averages		Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Per cent.
	4 years, 1876-1879	3 2	0 6	0 6 $\frac{1}{2}$	3 14 $\frac{1}{2}$	9.09
	4 years, 1880-1883	2 0 $\frac{1}{2}$	0 6	0 0 $\frac{1}{2}$	2 7 $\frac{1}{2}$	1.17
	4 years, 1884-1887	1 11	0 3 $\frac{1}{2}$	0 0 $\frac{1}{2}$	1 15 $\frac{1}{2}$	1.16
	12 years, 1876-1887	2 4 $\frac{1}{2}$	0 5 $\frac{1}{2}$	0 2 $\frac{1}{2}$	2 12 $\frac{1}{2}$	4.93
AMMONIUM SALTS = 86 lbs. NITROGEN, AND MIXED MINERAL MANURE. (Plot 7.)						
Averages		Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Per cent.
	4 years, 1876-1879	5 14	0 8 $\frac{1}{2}$	0 15 $\frac{1}{2}$	6 18	11.08
	4 years, 1880-1883	7 19 $\frac{1}{2}$	0 6 $\frac{1}{2}$	0 8 $\frac{1}{2}$	8 14 $\frac{1}{2}$	4.95
	4 years, 1884-1887	4 3 $\frac{3}{8}$	0 6 $\frac{1}{2}$	0 1 $\frac{1}{2}$	4 10 $\frac{1}{2}$	1.49
	12 years, 1876-1887	5 18 $\frac{1}{2}$	0 7 $\frac{1}{2}$	0 8 $\frac{1}{2}$	6 14 $\frac{1}{2}$	6.26
NITRATE OF SODA = 86 lbs. NITROGEN, AND MIXED MINERAL MANURE. (Plot 8.)						
Averages		Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Per cent.
	4 years, 1876-1879	5 19	0 8	0 18 $\frac{1}{2}$	7 5 $\frac{1}{2}$	12.82
	4 years, 1880-1883	7 10 $\frac{1}{2}$	0 6	0 7 $\frac{1}{2}$	8 4 $\frac{1}{2}$	4.70
	4 years, 1884-1887	4 2 $\frac{1}{2}$	0 5	0 1 $\frac{1}{2}$	4 9 $\frac{1}{2}$	1.73
	12 years, 1876-1887	5 17 $\frac{1}{2}$	0 6 $\frac{1}{2}$	0 9 $\frac{1}{2}$	6 13	7.00
SUMMARY. AVERAGE 12 YEARS. 1876-1887.						
Unmanured	1 13 $\frac{1}{2}$	0 5	0 1 $\frac{1}{2}$	1 19 $\frac{1}{2}$	3.15	
Superphosphate	3 5	0 5 $\frac{1}{2}$	0 2 $\frac{1}{2}$	3 13 $\frac{1}{2}$	3.66	
Mixed Mineral Manure ..	3 7 $\frac{1}{4}$	0 4 $\frac{1}{2}$	0 2 $\frac{1}{2}$	3 15 $\frac{1}{2}$	3.45	
Ammonium Salts alone ..	1 17 $\frac{1}{2}$	0 6 $\frac{1}{2}$	0 1 $\frac{1}{2}$	2 5 $\frac{1}{2}$	4.06	
Nitrate of Soda alone ..	2 4 $\frac{1}{2}$	0 5 $\frac{1}{2}$	0 2 $\frac{1}{2}$	2 12 $\frac{1}{2}$	4.93	
Ammonium Salts and Mixed Mineral Manure ..	5 18 $\frac{1}{2}$	0 7 $\frac{1}{2}$	0 8 $\frac{1}{2}$	6 14 $\frac{1}{2}$	6.26	
Nitrate of Soda and Mixed Mineral Manure ..	5 17 $\frac{1}{2}$	0 6 $\frac{1}{2}$	0 9 $\frac{1}{2}$	6 13	7.00	

mineral manure alone, with the ammonium salts and mixed mineral manure together, and with the nitrate of soda and the mixed mineral manure together, there was more produce over the second four years than over the first; but there was a marked reduction over the third four years. It is evident, therefore, that the falling off over the second four years in the other cases was not to be accounted for by less favourable seasons only. The conclusion is rather, that by the continuous growth of the crop without manure, or by nitrogenous manures alone, the available supplies of the necessary mineral constituents within the soil, became relatively deficient.

But the great decline over the third four years, under all conditions of manuring, even where there was a full supply of both nitrogen and mineral constituents, shows that the seasons were then less favourable for luxuriant growth. Doubtless, too, with the mineral manures alone, the available supply of nitrogen within the soil, and with the nitrogenous manures alone, the available supply of mineral constituents, had become deficient.

A point of considerable interest brought to view in the last column of the Table is, that there was, under every condition of manuring, a very much larger proportion of diseased tubers over the first four years, when the "Rock" was grown, than afterwards with the "Champion." The very bad result over the first four years was, however, doubtless in great measure due to the character of the seasons also, which included some exceedingly wet and unfavourable ones. With the "Champion," there was, upon the whole, a less proportion of diseased tubers over the third than over the second period of four years. It is true, that the later years were generally drier, and therefore less favourable, both for luxuriance of growth, and for the development of the disease. Nevertheless, it is of interest to observe that the amount of disease was not enhanced by the continuous growth of the crop on the same land, as is frequently assumed to be the case. It is further of interest to note that, with the highest manuring, and the most luxuriant growth, that is where ammonium salts or nitrate of soda, and the mixed mineral manures, were used together, there was, over the second four years, even with the "Champion," a much higher proportion of diseased tubers than with any of the other manures; though, over the third period, of drier seasons, the proportion was about as low as under the other conditions of manuring.

In the summary at the bottom of the Table is given the average produce over the total period of twelve years, under each of the different conditions as to manuring. It will suffice to call special attention to the column showing the total produce of tubers—good, small, and diseased—and to the last column, showing the average percentage of diseased tubers, under each condition of manuring.

In the first place, the average produce over twelve years without any manure, is not quite 2 tons per acre; and it will be remembered that there was a considerable decline from period to period under this exhausting treatment. Nevertheless, as will be seen further on, this

low yield without manure, for twelve years in succession on the same land, is about as much as the average produce under ordinary cultivation in the United States, and nearly two-thirds as much as in some important European countries.

By superphosphate of lime alone the produce is raised from an average of scarcely 2, to nearly $3\frac{1}{2}$ tons; and by a mixed mineral manure, containing, besides superphosphate of lime, salts of potash, soda, and magnesia, to just over $3\frac{1}{2}$ tons, that is to very little more than by the superphosphate alone. It is evident, therefore, that up to this amount of production, the character of the exhaustion induced by the growth of the crop on this land, which was, agriculturally speaking, in a somewhat exhausted condition, was much more that of available phosphoric acid than of potash, or the other bases.

In reference to this increase of produce of Potatoes by mineral manures alone, it may be observed that the result is quite consistent with that obtained with root-crops having comparatively shallow root-development; and in such cases the source of the nitrogen is chiefly the store of it in the surface soil. The beneficial effects of mineral manures, and especially of phosphates, are indeed observed generally with ripened as well as with succulent crops which are spring sown, and which have, with a short period of growth, comparatively superficial rooting, and which rely therefore much on the stores of the surface soil.

It is remarkable that there is much less increase of produce of Potatoes by nitrogenous manures alone than by mineral manures alone.

Thus, by ammonium salts alone there is an average produce of scarcely 2 tons 6 cwt., or only about 6 cwt. more than without manure; and with nitrate of soda alone there is an average of only 2 tons $12\frac{1}{2}$ cwt. per acre. The better result by nitrate of soda than by ammonium salts is doubtless due to the nitrogenous supply being more immediately available, and more rapidly distributed within the soil, and so inducing a more extended development of feeding root.

These negative results by the nitrogenous manures alone, confirm the conclusion that by the continuous growth of the crop on this land, it was the available supply of mineral constituents within the root-range of the plant, more than that of nitrogen, that became deficient.

The last two lines of the Table show, that with the mixed mineral manure and ammonium salts together, there was an average of about 6 tons $14\frac{1}{2}$ cwt., and with the mixed mineral manure and the same amount of nitrogen as nitrate of soda, an average of 6 tons 13 cwt.; that is, nearly twice as much as with the mineral manure alone, and much more than twice as much as with the nitrogenous manure alone. These amounts, it may be observed, are higher than the estimated average produce of either Division of the United Kingdom; indeed, more than one and a half time as high as in Ireland in recent years. At any rate the amounts of produce obtained by the mixture of both mineral and nitrogenous manures are sufficient to show that, although the land is by no means specially adapted for Potatoes, the results may

be taken as normal and trustworthy ; and as fairly indicating the characteristic manurial requirements of the crop ; and the conclusion is that, in an agriculturally exhausted soil, both mineral and nitrogenous manures are required to give full crops.

Finally, in reference to this summary of the results, the last column shows the average percentage of diseased tubers under each of the several conditions as to manuring. It is seen that, without manure, and with purely mineral manures, the proportion of diseased tubers is much less than where nitrogenous manures were applied ; and again, that it was less where the nitrogenous manures were applied alone, than when in conjunction with mineral manures ; and where, consequently, the luxuriance of growth, and the amounts of produce, were the greatest. To this result I shall have to refer again further on.

PRODUCE WITHOUT MANURE, AND WITH FARM-YARD MANURE.

Table II. (p. 7), gives the results obtained by farm-yard manure, alone, or with other manures, compared with those without manure. It will be seen that the average produce per acre, per annum, is not, as in the case of the artificial manure series, given for the first, second, and third periods of four years each, and for the twelve years, but for six, six, and twelve years ; there having been, as the Table shows, a change in the manuring, in two cases after six years, and in the third after seven years ; and, for comparison with the manured plots, the produce without manure is now also given for six, six, and twelve years. It is to be understood, however, that, as in the other experiments, so in these, the "Rock" was grown in the first four years, and the "Champion" afterwards.

As before, we may confine detailed attention to the column of average total produce of tubers—good, small, and diseased, together—and to the last column, showing the average percentage of diseased Potatoes in the total produce.

As already shown, the average produce without manure declined considerably over the later years.

The second division of the Table shows that, with an annual application of 14 tons farm-yard manure per acre, supplying perhaps about 200 lbs. of nitrogen per acre per annum, there was an average produce over six years of only about $5\frac{1}{2}$ tons ; and, as shown in the third division, the addition of superphosphate of lime raised the produce to scarcely 5 tons 12 cwt., or by only about 7 cwt. The fourth division shows, however, that by the further addition of nitrate of soda, supplying 86 lbs. of nitrogen per acre per annum, in a much more readily available condition than most of that in the farm-yard manure, the average annual produce of tubers was raised to 7 tons 2 cwt., or by $1\frac{1}{2}$ ton more.

Comparing these results with those obtained by artificial manures alone, we find that farm-yard manure, which, besides an abundance of mineral matters, and a large amount of organic substance rich in carbon,

supplied annually about 200 lbs. of nitrogen, gave considerably less produce than an artificial mixture of mineral manures and ammonium salts or nitrate of soda, supplying only 86 lbs. of nitrogen per acre per annum. The fact is, that it is only the comparatively small proportion of the nitrogen of farm-yard manure which is due to the liquid dejections of the animals, that is in a readily and rapidly available condition; whilst that due to more or less digested matter passing in the fæces, is more slowly available, and that in the litter remains a very long time inactive. Hence, the addition of nitrogen as nitrate of soda to the farm-yard manure had a very marked effect.

TABLE II.
POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Manures and Produce per acre per annum; 12 years, 1876-1887.

	Good.	Small.	Diseased.	Total.	Per cent. Diseased in Total.	
UNMANURED, 12 years. (Plot 1.)						
Averages {	Tons. cwts.	Tons. cwts.	Tons. cwts.	Tons. cwts.	Per cent.	
	6 years, 1876-1881	1 17½	0 5½	0 2	2 5½	4·27
	6 years, 1882-1887	1 9	0 4½	0 0½	1 13½	1·63
	12 years, 1876-1887	1 13½	0 5	0 1½	1 19½	3·15
FARM-YARD MANURE, 6 YEARS; UNMANURED, 6 YEARS. (Plot 2.)						
Averages {	6 years, 1876-1881	4 11½	0 7	0 5½	5 4½	5·54
	6 years, 1882-1887	2 13½	0 6½	0 1½	3 1	2·88
	12 years, 1876-1887	3 12½	0 6½	0 3½	4 2½	4·56
FARM-YARD MANURE AND SUPERPHOSPHATE, 7 YEARS; FARM-YARD MANURE ALONE, 5 YEARS. (Plot 3.)						
Averages {	6 years, 1876-1881	4 16½	0 7½	0 7½	5 11½	6·73
	6 years, 1882-1887	3 17½	0 5½	0 2½	4 5½	2·58
	12 years, 1876-1887	4 7½	0 6½	0 4½	4 18½	4·93
FARM-YARD MANURE, SUPERPHOSPHATE, AND NITRATE OF SODA, 6 YEARS; FARM-YARD MANURE ALONE, 6 YEARS. (Plot 4.) (*)						
Averages {	6 years, 1876-1881	5 17½	0 6½	0 17½	7 2½	12·56
	6 years, 1882-1887	3 13	0 5½	0 1½	4 0½	2·21
	12 years, 1876-1887	4 15½	0 6½	0 9½	5 11½	8·82
SUMMARY. AVERAGE 12 YEARS, 1876-1887.						
Unmanured	1 13½	0 5	0 1½	1 19½	3·15	
Farm-yard Manure, 6 years; ..	3 12½	0 6½	0 3½	4 2½	4·56	
Unmanured, 6 years						
Farm-yard Manure and Superphosphate, 7 years; ..	4 7½	0 6½	0 4½	4 18½	4·93	
Farm-yard Manure alone, 5 years						
Farm-yard Manure, Superphosphate, and Nitrate ..	4 15½	0 6½	0 9½	5 11½	8·82	
Soda, 6 years; Farm-yard ..						
Manure alone, 6 years (*) ..						

(*) The Superphosphate, but not the Nitrate, was applied in the seventh year, 1882.

The next point to consider is the effects of the residue of the previously applied manures, as shown in the second line of each division of the Table.

The second division shows that, after the application of farm-yard manure, containing about 200 lbs. of nitrogen per acre, for six years in succession, there was, over the next six years without manure, a falling off in the annual average produce of tubers from nearly $5\frac{1}{2}$ to little over 3 tons;—that is, to less than the average produce obtained by artificial mineral manures without any nitrogen. There is here striking evidence of the very slow action of the large residue, mineral as well as nitrogenous, of the farm-yard manure.

The third division shows that with the cessation of the addition of superphosphate to the farm-yard manure, the crop was reduced from 5 tons 12 cwt. to 4 tons 5 cwt. It is true that the later seasons were less favourable for luxuriance. Still, the evidence points to the conclusion that the residue of the superphosphate had comparatively little effect; and that, in fact, it remained within the soil in a condition only slowly available.

Lastly, the fourth division shows that with the cessation of the application of the nitrate of soda, the average produce was reduced from 7 tons 2 cwt. to only 4 tons, or by more than 3 tons per acre per annum. Allowing for the difference in the character of the seasons, there would still appear to have been practically no immediately available residue of the nitrogen of the nitrate left within the root-range of the crop.

The fact that, over the last six years, farm-yard manure, together with the residue of previously applied farm-yard manure, superphosphate, and nitrate of soda, only yielded an average of about 4 tons of tubers; and that farm-yard manure and the residue of farm-yard manure and superphosphate, only gave about $4\frac{1}{2}$ tons, whilst farm-yard manure alone gave over the first six years $5\frac{1}{2}$ tons, is clear indication that the later seasons were somewhat less favourable for luxuriance with such manures.

As in the case of the artificial manures, so now with the farm-yard manure series, the last column of the Table shows a very much larger proportion of diseased tubers over the earlier than over the later years; and, consistently with the results with the artificial manures, there is the largest proportion where there was the largest supply of nitrogen; that is where nitrate of soda was added to the farm-yard manure. In comparing period with period, however, it must not be forgotten that the "Rock" was grown in the first four years, and the "Champion" afterwards.

The summary given at the foot of the Table shows the average results for each of the farm-yard manure plots, over the whole period of twelve years. The results have, of course, to be read with due reference to the changes in the manuring over the later years, and hence are not very direct in their indications.

It is somewhat remarkable that on neither plot with farm-yard

manure, not even where it was applied each year of the twelve, was there so much produce as on the artificially manured plots receiving both mineral and nitrogenous manures. Indeed, not even where nitrate of soda was applied in addition to the farm-yard manure during the first six years, did the average produce of the twelve years amount to six tons of tubers.

The last column of the summary shows, as before, that the proportion of diseased tubers was the greater, the greater the amount of nitrogen supplied, and the greater the luxuriance.

Upon the whole it is obvious that, in the case of this somewhat agriculturally exhausted arable land, mineral manures alone had more effect than nitrogenous manures alone; but that, mineral constituents being adequately supplied, the further addition of nitrogenous manures was essential to obtain anything like full crops.

CONSTITUENTS IN THE CROPS PER ACRE PER ANNUM.

1.—*Artificial Manure Series.*

It will be of interest next to consider, what is the increased amount of some of the more important constituents of the tubers stored up in the crop, under the influence of the different manures; and especially what is the increased amount of them stored up, for a given quantity of nitrogen supplied in manure. Results of the analyses of the various crops, to which I shall call special attention when considering the percentage composition of the tubers, supply the data for estimates on these points.

Table III. (p. 10), gives the results for the artificially manured series.

The upper division of the Table shows the amounts, in lbs., of total dry or solid matter, of nitrogen, of total mineral matter (or ash), of potash, of phosphoric acid, of sulphuric acid, and of chlorine, in the average produce, per acre, per annum, over the twelve years, without manure, and with each of the six different artificial manures. These are the total quantities in the crops per acre; but the amount of seed Potatoes planted would, on the average, supply to the soil perhaps as much as one-third or more of the various constituents as were removed in the unmanured produce; and, of course, the same actual amounts, but a much less proportion of the whole in the produce, would be supplied in the case of the manured crops. It seems desirable, however, that the Table should give the actual amounts in the crops, rather than any mere estimates founded on uncertain data; especially as the figures in the remaining divisions of the Table, which relate to the increase of constituents in the crops under the influence of the different manures, would not be affected by any correction for the amounts supplied in the seed.

In the second division are given the increased amounts of each of the same constituents per acre in the average produce of each of the manured plots, over the amount in the unmanured produce.

The third division shows the amounts of the several constituents in

the increase of produce over that without manure, for 100 of nitrogen supplied in manure.

In the fourth division are shown the actual amounts of increase of the constituents per acre by the nitrogenous and mineral manure together, over those by the mineral manure alone; and the fifth and last division shows these increased amounts over those by the mineral manure alone, calculated for 100 of nitrogen supplied in manure.

TABLE III.
EXPERIMENTS ON POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Constituents per acre per annum in Total Tubers. Average of 12 years, 1876-1887.

	Dry Matter.	Nitrogen.	Mineral Matter (Ash).	Potash.	Phos- phoric Acid.	Sul- phuric Acid.	Chlorine.
CONSTITUENTS PER ACRE PER ANNUM.							
Unmanured	1250	14.9	37.4	20.8	5.51	3.25	1.99
Superphosphate.. ..	2203	20.5	87.9	50.8	11.28	4.97	4.13
Mixed Mineral Manure	2235	19.9	93.6	53.9	11.91	5.75	4.44
Ammonium Salts	1343	19.7	39.5	21.6	4.74	3.23	3.70
Nitrate of Soda.. ..	1558	23.0	44.1	23.1	5.59	3.15	1.83
Ammonium Salts and Mixed Mineral Manure	3857	48.1	153.7	88.3	16.80	8.30	11.02
Nitrate of Soda and Mixed Mineral Manure	3844	50.8	149.0	85.2	17.51	8.61	4.16
INCREASE OF CONSTITUENTS PER ACRE PER ANNUM OVER UNMANURED.							
Superphosphate.. ..	953	5.6	50.5	30.0	5.77	1.72	2.14
Mixed Mineral Manure	985	5.0	56.2	33.1	6.40	2.50	2.45
Ammonium Salts	93	4.8	2.1	0.8	-0.77	-0.02	1.71
Nitrate of Soda.. ..	308	8.1	6.7	2.3	0.08	-0.10	-0.16
Ammonium Salts and Mixed Mineral Manure	2607	33.2	116.3	67.5	11.29	5.05	9.03
Nitrate of Soda and Mixed Mineral Manure	2594	35.9	111.6	64.4	12.00	5.36	2.17
INCREASE OF CONSTITUENTS FOR 100 NITROGEN IN MANURE OVER UNMANURED.							
Ammonium Salts	108	5.6	2.4	0.9	-0.90	-0.02	1.99
Nitrate of Soda.. ..	358	9.4	7.8	2.7	0.09	-0.12	-0.19
Ammonium Salts and Mixed Mineral Manure	3031	38.6	135.2	78.5	13.13	5.87	10.50
Nitrate of Soda and Mixed Mineral Manure	3016	41.7	129.8	74.9	13.95	6.23	2.52
INCREASE OF CONSTITUENTS PER ACRE PER ANNUM OVER MIXED MINERAL MANURE.							
Ammonium Salts and Mixed Mineral Manure	1622	28.2	60.1	34.4	4.89	2.55	6.58
Nitrate of Soda and Mixed Mineral Manure	1609	30.9	55.4	31.3	5.60	2.86	-0.28
INCREASE OF CONSTITUENTS FOR 100 NITROGEN IN MANURE OVER MIXED MINERAL MANURE.							
Ammonium Salts and Mixed Mineral Manure	1886	32.8	69.9	40.0	5.69	2.97	7.65
Nitrate of Soda and Mixed Mineral Manure	1871	35.9	64.4	36.4	6.51	3.33	-0.33

Referring to the first division, it is seen that whilst without manure there is an average of only 1250 lbs., or little more than 11 cwt. of total dry or solid matter, produced per acre, there is not much more (1343 lbs.) with purely nitrogenous manure as ammonium salts, and scarcely one-fourth more (1558 lbs.) with the same amount of nitrogen as nitrate of soda. There is, on the other hand, with the purely mineral manures, nearly 20 cwt. (2203 and 2235 lbs.), and with the nitrogenous and mineral manures together an average of about $34\frac{1}{2}$ cwt. (3857 and 3844 lbs.) of solid matter produced per acre per annum.

The average amount of nitrogen annually stored up in the tubers grown without manure was, notwithstanding the amount supplied in the seed, only 14.9 lbs.; or less than would be yielded in wheat or barley under similar circumstances. By mineral manures alone the amount was raised to about 20 lbs., or to nearly as much as in wheat or barley under the same conditions. On the other hand, the direct application of 86 lbs. of nitrogen, per acre per annum, when as ammonium salts alone, only raised the amount taken up to 19.7 lbs., and when as nitrate of soda alone, to only 23.0 lbs. The incapacity of the plant to avail itself of the supplied nitrogen in the absence of a sufficient available supply of mineral constituents, is here very strikingly illustrated. With the same applications of nitrogen, but in conjunction with the mixed mineral manure, the amount of nitrogen stored up in the tubers is raised from about 20 to about 50 lbs.;—48.1 lbs. with the ammonium salts, and 50.8 lbs. with the nitrate of soda.

The remaining columns of the upper division of the Table show that very little more of either the total, or the individual, mineral constituents, was taken up under the influence of the purely nitrogenous manures, than without manure. With the mineral manures alone, however, there was more than twice as much, both of total mineral constituents, and of the more important individual ones, taken up; and there was three or four times as much taken up when the nitrogenous and the mineral manures were used together. The figures relating to potash and phosphoric acid afford striking illustrations on these points.

The influence of the manures on the amounts of constituents taken up by the crop is, however, brought out more clearly still in the second division of the Table, which shows the amounts of each constituent stored up more than without manure.

It is seen that, whilst the purely nitrogenous manures have but little increased the production of solid matter, the mineral manures alone have increased it by nearly 1000 lbs. (953 and 985 lbs.) per acre, and the nitrogenous and mineral manures together have increased it by about 2600 lbs. (2607 and 2594 lbs.), or by more than 23 cwt. per acre.

It is remarkable that the purely nitrogenous manures, supplying 86 lbs. of nitrogen, have scarcely increased the assimilation of nitrogen more than the purely mineral manures; whilst the application of the two together has increased it very much—by 33.2 and 35.9 lbs. These latter amounts, when calculated for 100 nitrogen supplied in manure, as

shown in the third division of the Table, represent a recovery in the increase of the crop of 38·6 and 41·7 per cent. of the nitrogen supplied in the manure. But when the increased assimilation of nitrogen is calculated; not over the amount in the unmanured produce, but over that in the produce by the mixed mineral manure alone, it represents, as shown in the bottom division, only 32·8 and 35·9 per cent. recovered.

These amounts of nitrogen recovered in the increased produce of Potatoes, for 100 supplied in manure, are less than were so recovered in Mangel Wurzel receiving similar manures. Thus the amount of nitrogen recovered for 100 supplied (with mineral manures) when as ammonium salts, was with Mangel Wurzel 42·3, against only 32·8 with Potatoes; and when the supply was as nitrate of soda, 59·9 per cent. of the nitrogen was recovered as increase in the Mangel Wurzel, against only 35·9 per cent. with the Potatoes. The proportion recovered in Potatoes is, however, approximately the same as in the case of Wheat, but less than that in the case of the spring sown Barley.

Referring in less detail to the amounts of other constituents taken up under the influence of the different manures, it is seen that by far the most prominent increase is in the potash, and second in order comes phosphoric acid. It is remarkable that, by the use of superphosphate of lime alone, 30 lbs. more potash are taken up per acre than without manure, and that only 3 lbs. more are taken up under the influence of the mixed mineral manure alone, which, besides superphosphate, supplied annually nearly 150 lbs. of potash. It is well known that one special effect of superphosphate of lime applied to spring sown crops, is greatly to increase the development of feeding-root within the surface soil; and here it would seem that under its influence, probably on both soil and plant, the Potato has been enabled to obtain a large amount of potash from the stores of the surface soil.

The purely nitrogenous manures, on the other hand, have not enabled the plant to take up an appreciably increased amount of potash.

It is, however, where the mineral and nitrogenous manures were applied together, that the greatest amount of potash is taken up. Indeed, under the influence of this combination, nearly one-half of the 150 lbs. of potash annually supplied is recovered in the increased produce, 67·5 lbs. in one case, and 64·4 lbs. in the other.

But little is definitely known of the special function of individual mineral constituents in vegetation. It is, however, pretty clearly established that the presence of potash is essential for the formation of the chief non-nitrogenous matters—starch and sugar. The published results of experiments at Rothamsted have shown that the proportion of potash in the ash of wheat was the greater, the better matured the grain—that is the larger the proportion of starch it contained; and here in the potato we find a greatly increased amount of potash in the heaviest crops, that is to say in those in which the largest amounts of starch have been formed.

The accumulation of phosphoric acid, on the other hand, is more directly connected with the assimilation of nitrogen, and the formation

of the nitrogenous compounds. The amounts of phosphoric acid are seen to be much less than those of potash; but the differences in the amounts bear an obvious, though not a numerically direct, relation, to the differences in the amounts of nitrogen in the crops.

Sulphuric acid is also essential, as a supply of sulphur, to the formation of certain nitrogenous constituents of the plant. It is seen that the quantities are considerably less than those of phosphoric acid, and that the variations have some, but not a numerically direct connection with the amounts of nitrogen in the crops. It is to be borne in mind, however, that the methods of preparing ashes for analysis, do not in all cases secure the retention in them, as sulphuric acid, of the whole of the sulphur in the substance incinerated. On the other hand, the ashes, especially of other than such fixed products as ripened seeds, generally contain sulphuric acid existing as such in the crude product.

The amounts of the chlorine taken up by the plant are very variable, and have relation chiefly to the supplies by manure, and probably none to the formation of any organic compounds.

2.—*Farm-yard Manure Series.*

Let us now turn to the consideration of similar particulars relating to the farm-yard manure series of plots—that is to what may be called the chemical statistics of the crops.

Table IV. (p. 14) gives the results for the first and second periods of six years each, separately; also the difference between the two, or the results for the twelve years, as the case may be.

It is seen that, without manure, there is less of every constituent stored up in the crop over the second than over the first period of six years. This reduction of course represents exhaustion, as well as any influence of the seasons. In the case of each of the manured plots, the whole, or some item, of the manure, was omitted over the second period, so that some reduction in the yield would be anticipated; and it is seen that there was, under each condition of manuring, a reduction, and generally a very great reduction, in the amount stored up of every constituent, with the exception of the nitrogen in one case, as indicated by the + sign.

The upper division of the Table shows the actual quantities of the several constituents stored up per acre; but the significance of the facts will be better appreciated by an examination of the increased amounts over those without manure, as given in the second division of the Table.

It will be remembered that the quantity of farm-yard manure annually applied per acre was estimated to contain about 200 lbs. of nitrogen, besides a very large amount of mineral constituents. Yet, in no case was the increased yield of solid substance in the crop so great as was obtained by an artificial mixture of mineral and nitrogenous manure, supplying only 86 lbs. of nitrogen, but in a more readily available condition. Nor was the increased assimilation of any one of

RESULTS OF EXPERIMENTS AT ROTHAMSTED,

TABLE IV.
EXPERIMENTS ON POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.
Constituents per acre per annum in Total Tubers. 12 years, 1876-1887.

	Dry Matter.	Nitrogen.	Mineral Matter (Ash).	Potash.	Phosphoric Acid.	Sulphuric Acid.	Chlorine.
CONSTITUENTS PER ACRE PER ANNUM.							
Unmanured ... { 6 yrs., 1876-81	lbs. 1413	lbs. 15.4	lbs. 45.4	lbs. 25.2	lbs. 6.68	lbs. 3.95	lbs. 2.42
... { 6 yrs., 1882-87	1079	13.9	30.4	16.8	4.47	2.64	1.62
Difference...	334	1.5	15.0	8.4	2.21	1.31	0.80
Farmyard Manure ... { 6 yrs., 1876-81	3022	28.2	117.1	67.2	14.82	6.77	8.38
Unmanured ... { 6 yrs., 1882-87	1944	24.3	58.8	33.8	7.45	3.40	4.21
Difference...	1078	3.9	58.3	33.4	7.37	3.37	4.17
Farmyard Manure and Superphosphate { 6 yrs., 1876-81	3188	29.0	130.0	74.7	15.51	7.61	10.27
Farmyard Manure alone ... { 6 yrs., 1882-87	2512	33.6	91.6	52.6	10.92	5.36	7.23
Difference...	676	+ 4.6	38.4	22.1	4.59	2.25	3.04
Farmyard Manure, Superphosphate, and Nitrate ... { 6 yrs., 1876-81	3886	48.7	148.1	83.7	17.95	9.00	6.92
Farmyard Manure alone ... { 6 yrs., 1882-87	2327	33.4	84.5	47.7	10.24	5.14	3.95
Difference...	1559	15.3	63.6	36.0	7.71	3.86	2.97
INCREASE OF CONSTITUENTS PER ACRE PER ANNUM OVER UNMANURED.							
Farmyard Manure ... { 6 yrs., 1876-81	1809	12.8	71.7	42.0	8.14	2.82	5.96
Farmyard Manure—Residue ... { 6 yrs., 1882-87	865	10.4	28.4	17.0	2.98	0.76	2.59
Difference...	744	2.4	43.3	25.0	5.16	2.06	3.37
Farmyard Manure and Superphosphate { 6 yrs., 1876-81	1775	13.6	84.6	49.5	8.83	3.66	7.85
Farmyard Manure and Residue.. { 6 yrs., 1882-87	1433	19.7	61.2	35.8	6.45	2.72	5.61
Difference...	342	+ 6.1	23.4	13.7	2.38	0.94	2.24
Farmyard Manure, Superphosphate, and Nitrate ... { 6 yrs., 1876-81	2473	33.3	102.7	58.5	11.27	5.05	4.50
Farmyard Manure and Residue.. { 6 yrs., 1882-87	1248	19.5	54.1	30.9	5.77	2.50	2.33
Difference...	1225	13.8	48.6	27.6	5.50	2.55	2.17
INCREASE OF CONSTITUENTS FOR 100 NITROGEN IN MANURE OVER UNMANURED.							
Farmyard Manure ... { 6 yrs., 1876-81	805	6.4	35.9	21.0	4.07	1.41	2.98
Farmyard Manure—Residue ... { 6 yrs., 1882-87	432	5.2	14.2	8.5	1.49	0.38	1.30
12 years...	1237	11.6	50.1	29.5	5.56	1.79	4.28
Farmyard Manure and Superphosphate { 6 yrs., 1876-81	888	6.8	42.3	24.8	4.42	1.83	3.92
Farmyard Manure, and Residue.. { 6 yrs., 1882-87	717	9.9	30.6	17.9	3.23	1.36	2.81
12 years...	802	8.3	36.5	21.3	3.82	1.60	3.37
INCREASE OF CONSTITUENTS FOR 100 NITROGEN AS NITRATE, OVER FARMYARD MANURE AND SUPERPHOSPHATE.							
Farmyard Manure, Superphosphate, and Nitrate ... { 6 yrs., 1876-81	812	22.9	21.0	10.5	2.84	1.62	-3.90

the individual constituents, so great under the influence of the farm-yard manure, as when these were applied in the rapidly available condition as in the artificial mixtures.

It has been seen that, with the artificial manures, there was, of the nitrogen supplied, about 40 per cent. recovered in the increased crop (38.6 and 41.7) reckoned over the produce without manure, and about 34.5 per cent. (32.8 and 35.9) reckoned over the produce by purely mineral manures. But here, when the supply was in farm-yard manure, there was, as the third division of the Table shows, in one case only 6.4, and in another only 6.8 per cent. of the nitrogen so supplied, recovered in the immediate increase over the six years of the application; and, notwithstanding the great accumulation that would take place, there was only 8.3 per cent. recovered in the increase when the application was continued for 12 consecutive years.

It is further seen that after farm-yard manure had been applied for six years in succession, and it had yielded up to the crop only 6.4 per cent. of its nitrogen, over the next six years without manure, the large unrecovered residue only yielded 5.2 per cent. more; that is, only 11.6 per cent. in all, over the twelve years.

In the case of other crops it has been found that only a small proportion of the nitrogen of farm-yard manure was taken up in the year of the application. But these results seem to indicate that the Potato is able to avail itself of a less proportion of the nitrogen of the manure than any other farm crop. Yet, in ordinary practice, farm-yard manure is not only largely relied upon for Potatoes, but is often applied in larger quantity for them than for any other crop. It is probable that, independently of its liberal supply of all necessary constituents, its beneficial effects are in a considerable degree due to its influence on the mechanical condition of the soil, rendering it more porous and easily permeable to the surface roots, upon the development of which the success of the crop so much depends. Then, again, something may be due to an increased temperature of the surface soil engendered by the decomposition of so large an amount of organic matter within it; whilst the carbonic acid evolved in the decomposition will, with the aid of moisture, serve to render the mineral resources of the soil more soluble.

The Potato is, indeed, largely a kitchen and market garden crop, as well as a farm crop; and for the production of garden vegetables generally very large quantities of farm or stable manure are applied, beyond what is required as a mere supply of constituents to the crops—the process being to a great extent one of forcing, as above referred to; and a necessary result is a great accumulation of unexhausted residue within the soil.

It will be of interest to give here a few illustrations of the manuring and produce of potatoes, in some localities where they constitute an important item of production.

I will first refer to the evidence given before *The Select Committee on the Potato Crop*. The practice of several growers in Forfarshire is

given. According to the various statements, the crop is generally grown in six, seven, or eight year rotation ; and farm-yard, or stable manure, is largely relied upon ; but it is frequently supplemented by liberal dressings of artificial manures, both mineral and nitrogenous. The quantity of dung used ranges from 12 to 14, and even to more than 20 tons per acre ; and sometimes as much as 10 cwt. of artificial manure is also used, consisting chiefly of superphosphate or dissolved bones, and potash salts, or kainit ; and six tons is reckoned a fair crop. In East Lothian the crop is also grown in six, seven, or eight year rotation ; as much as 30 tons of dung is used for the late crop, with 5 to 10 cwt. of artificials, consisting of guano or dissolved bones, and sometimes potash salts ; and the crop is estimated at 6 to 8 tons per acre. For an early crop as much as 40 tons of dung, and 10 cwt. of a mixture of superphosphate, guano, and dissolved bones, are used, and only about 4 or 5 tons of produce is obtained. It was stated that, in Dublin County, potatoes are grown in four or five years course, with dung and artificials ; the latter consisting of superphosphate, potash salts, and salts of ammonia or nitrate of soda ; and 8 tons is considered a good crop. In Kent, one witness reports the growth of the crop once in five years, using 12 to 20 loads of farm-yard manure, with superphosphate, kainit, and sulphate of ammonia ; and getting 10 to 11 tons of marketable tubers, and 2 tons of small. In another case in Kent 30 to 35 tons of dung are used.

Mr. T. H. Middleton, of Invergordon, Ross-shire, has kindly furnished me with further particulars as to the manuring and produce of potatoes in Scotland. He states that it is common to use 15 to 20 tons of farm-yard manure, with bone meal and superphosphate in addition. Or, sometimes, Potatoes are grown with artificial manure only ; about 10 cwt., consisting of 3 cwt. superphosphate, 2 cwt. bone meal, 3 cwt. of kainit, and 2 cwt. sulphate of ammonia ; and an average crop is about $6\frac{1}{2}$ tons of Regents, or $7\frac{1}{2}$ tons of Magnum Bonums. At a farm in Ayrshire, the practice for the growth of an early crop is to use 20 to 30 tons of dung, with 5 cwt. of kainit, and 8 or 10 cwt. of other artificial manures, consisting of good guano, or phosphatic guano with sulphate of ammonia, or any mixture containing 8 to 10 per cent. of ammonia, 20 to 30 per cent. of phosphate, and 3 to 5 per cent. of potash. In Forfarshire the crop is usually grown in an eight year course ; 15 to 20 tons of farm-yard manure are used, with artificial manures in addition ; 6 or 7 tons is reckoned an average crop, 10 tons a very good one, and 4 to 5 tons a bad crop. Sometimes, however, Potatoes are grown after three years grass, with artificial manures alone. In East and Mid Lothian, Potatoes are generally grown in a six year course ; with about 20 tons of farm-yard manure, and artificial manures in addition. The description of the latter varies considerably ; but the following is sometimes used :—2 cwt. ground bones, 1 cwt. vitriolized bones, $1\frac{1}{2}$ cwt. mineral superphosphate, 1 cwt. sulphate of potash, and $\frac{1}{2}$ cwt. sulphate of ammonia—in all 6 cwt. An average crop is 6 or 7 tons, and in very favourable seasons 10 or even 12 tons

are obtained. Sometimes, however, in the Lothians, Potatoes are grown in six year course, after two years grass, and with artificial manure only, the farm-yard manure being reserved for the Turnips.

Such are typical cases of the manuring and produce of Potatoes when grown as a farm rotation crop. But it will be well to consider the conditions under which the crop is grown in a specially suitable climate for the early market. On this point I have been favoured with a very interesting account of Potato growing in Jersey, by Mr. F. Woodland Toms, the Official Analyst, of St. Heliers. The rents for suitable land are very high. No special rotation is followed. Potatoes are grown two or three years, then corn, then grass for a few years, and then Potatoes again. From 25 to 30 tons of farm-yard manure, or seaweed, are applied per acre, with 8 to 12 cwt. of artificial manure, containing about 8 per cent. of ammonia, and 20 per cent. of soluble phosphate. Including rent, the total expenditure for the crop is often as much as £45 per acre, and sometimes even more; but almost always a second crop of some kind is taken the same year, after the removal of the Potatoes. The earliest crops, which command very high prices, average about 6 tons. But the average crop of the year ranges from 8 to 10 tons, according to season, with an average price of about £6 per ton. The price fluctuates, however, considerably, from season to season, and very much more throughout the season. Thus, it ranged, in 1886, from £10 per ton about the middle of June, to £3 11s. 6d. in the middle of August; in 1887, from £22 10s. at the end of May, to £6 11s. at the end of August; and in 1888, from £20 12s. 6d. at the beginning of June, to about £2 6s. in September and October. (*)

Lastly, Mr. C. B. Edwardes, of Peterborough, informs me that the market gardeners in the neighbourhood of Sandy, St. Neots, and Biggleswade, frequently apply from 30 to 60 tons of London stable manure per acre, for Potatoes, and even as much as 100 tons have, in some cases, been used. Frequently, too, besides the dung, $\frac{1}{2}$ to 1 ton of artificial manure, or from 100 to 200 bushels of soot, are also used.

It will be seen that the foregoing statements of the actual practice in the growth of Potatoes, in different localities, are quite consistent with the experimental results that have been adduced, in showing how large is the amount of manure required in proportion to the amount of produce obtained.

INFLUENCE OF SEASON AND MANURING ON THE PERCENTAGE COMPOSITION OF THE TUBERS.

The next point to consider is the percentage composition of the Potato, and the direction, and the degree, in which this is influenced

(*) Since the above was in type, my attention has been called to Mr. W. E. Bear's article, entitled, *Glimpses of Farming in the Channel Islands*, in the last number of the Journal of the Royal Agricultural Society. He there gives a very interesting account of the farming in Jersey, and especially of the treatment and produce of the potato crop, and to this I would refer for further details on the subject.

TABLE V.
EXPERIMENTS ON POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.
Mean percentage composition of the Good Tubers; 12 years, 1876-1887.

		Specific gravity of the Tubers.	Per cent. in Fresh Tubers.			Per cent. in Dry Matter.		
			Dry Matter.	Mineral Matter (Ash).	Nitrogen.	Mineral Matter (Ash).	Nitrogen.	
UNMANURED. (Plot 1.)								
Averages	{	4 years, 1876-1879	1.107	26.8	0.92	0.260	3.48	0.979
		4 years, 1880-1883	1.125	29.3	0.81	0.345	2.77	1.176
		4 years, 1884-1887	1.122	28.2	0.79	0.397	2.82	1.408
		12 years, 1876-1887	1.118	28.1	0.84	0.334	3.02	1.188
	SUPERPHOSPHATE OF LIME. (Plot 9.)							
Averages	{	4 years, 1876-1879	1.102	24.4	1.13	0.197	4.64	0.805
		4 years, 1880-1883	1.122	28.2	1.06	0.226	3.76	0.806
		4 years, 1884-1887	1.121	27.8	1.02	0.325	3.67	1.165
		12 years, 1876-1887	1.115	26.8	1.07	0.249	4.02	0.925
	MIXED MINERAL MANURE. (Plot 10.)							
Averages	{	4 years, 1876-1879	1.102	24.2	1.15	0.189	4.74	0.782
		4 years, 1880-1883	1.121	28.0	1.09	0.222	3.89	0.794
		4 years, 1884-1887	1.118	27.3	1.09	0.297	4.00	1.090
		12 years, 1876-1887	1.114	26.5	1.11	0.236	4.21	0.888
	AMMONIUM SALTS = 86 lbs. NITROGEN. (Plot 5.)							
Averages	{	4 years, 1876-1879	1.099	23.4	0.75	0.298	3.23	1.280
		4 years, 1880-1883	1.116	27.8	0.80	0.386	2.89	1.390
		4 years, 1884-1887	1.114	27.3	0.76	0.468	2.77	1.717
		12 years, 1876-1887	1.110	26.2	0.77	0.384	2.96	1.462
	NITRATE OF SODA = 86 lbs. NITROGEN. (Plot 6.)							
Averages	{	4 years, 1876-1879	1.104	24.6	0.74	0.314	3.03	1.282
		4 years, 1880-1883	1.117	27.9	0.78	0.399	2.81	1.431
		4 years, 1884-1887	1.115	27.2	0.73	0.463	2.70	1.707
		12 years, 1876-1887	1.112	26.5	0.75	0.392	2.84	1.473
	AMMONIUM SALTS = 86 lbs. NITROGEN, AND MIXED MINERAL MANURE. (Plot 7.)							
Averages	{	4 years, 1876-1879	1.096	24.0	1.06	0.250	4.44	1.054
		4 years, 1880-1883	1.110	26.6	0.99	0.305	3.72	1.149
		4 years, 1884-1887	1.107	26.2	1.01	0.401	3.85	1.535
		12 years, 1876-1887	1.104	25.6	1.02	0.319	4.00	1.246
	NITRATE OF SODA = 86 lbs. NITROGEN, AND MIXED MINERAL MANURE. (Plot 8.)							
Averages	{	4 years, 1876-1879	1.100	24.4	1.06	0.265	4.37	1.096
		4 years, 1880-1883	1.115	26.6	0.97	0.339	3.70	1.273
		4 years, 1884-1887	1.110	26.3	0.95	0.419	3.62	1.602
		12 years, 1876-1887	1.108	25.8	1.00	0.341	3.90	1.324
	SUMMARY. AVERAGE 12 YEARS, 1876-1887.							
Unmanured		1.118	28.1	0.84	0.334	3.02	1.188	
Superphosphate		1.115	26.8	1.07	0.249	4.02	0.925	
Mixed Mineral Manure		1.114	26.5	1.11	0.236	4.21	0.888	
Ammonium Salts alone		1.110	26.2	0.77	0.384	2.96	1.462	
Nitrate Soda alone		1.112	26.5	0.75	0.392	2.84	1.473	
Ammonium Salts and Mixed Mineral Manure		1.104	25.6	1.02	0.319	4.00	1.246	
Nitrate Soda and Mixed Mineral Manure		1.108	25.8	1.00	0.341	3.90	1.324	

by season and manuring. Table V. (p. 18) illustrates these points for the artificial manure series, and Table VI. (p. 21) for the farm-yard manure series. For each separate period, and for the total periods of the experiments, the particulars given are—the average specific gravity of the tubers; the percentages of dry or solid matter, of mineral matter, and of nitrogen, in the fresh tubers, also the percentages of mineral matter, and of nitrogen, in the dry substance of the tubers.

1.—*Artificial Manure Series.*

Referring to the Table (V.), it is seen that not only without manure, but with each of the six descriptions of artificial manure, the tubers have a higher specific gravity over the second and third, than over the first period of four years. It will be remembered that during the second and third periods the Champion was grown instead of the Rock as previously, and also that the earlier seasons were upon the whole much wetter, and therefore more conducive to luxuriance and less to maturation.

In countries where the Potato is largely grown for the manufacture of starch or potato spirit, the specific gravity serves as an important indication of quality. The higher the specific gravity, the greater as a rule is the proportion of dry matter, and the greater the proportion of starch. Indeed, Tables are constructed for the calculation of the percentage of dry matter, and of starch, from the specific gravity of the tubers.

Consistently, the Table shows that, with the higher specific gravity of the tubers over the second and third periods, there was, in every case, a considerably higher percentage of dry or solid matter over those periods, indicating better maturation.

Another point usually coincident with relatively high maturity of produce, is a relatively low percentage of mineral, or ash-constituents; and the figures show, in the majority of cases, a lower percentage of mineral matter in the fresh tubers, and in every case a considerably lower percentage in the dry substance of the tubers, over the second and third periods, than over the first period.

A low percentage of mineral matter in the dry substance of a crop, especially in the case of ripened products such as grain, and corn generally, does not as a rule indicate a defective amount of mineral matter, but the greater formation of organic substance in proportion to the mineral matter taken up; by which, of course, the percentage of the mineral matter in the dry substance is reduced—in other words, there is more favourable maturation.

Thus, then, the results relating to specific gravity, and to the percentages of dry substance, and of mineral matter, are perfectly consistent with the known comparative characters of the produce of the different periods.

It is not so, at first sight, so far as the nitrogen is concerned. There is, in every case, a considerably higher percentage of nitrogen in the fresh tubers, and in every case but one a higher percentage in the

dry substance of the tubers, over the second than over the first period, and in every case, both in the fresh and in the dry tubers, a higher percentage still over the third period.

Now in the case of the cereal grains, as a rule the better they are matured the lower is their percentage of nitrogen; the explanation being that maturation means the greater formation of the non-nitrogenous substance—starch—under the favourable ripening climatic conditions; and thus the already accumulated nitrogen shows a lower proportion to it, that is, a lower percentage. The same thing happens, though in a less marked degree, even in the case of the maturation of the succulent roots; the more there is of sugar accumulated, the lower is the percentage of nitrogen.

It will be seen further on that, in the case of the potato, more than 80 per cent. of the total nitrogen of the tuber exists in the juice, that is not in the fixed or insoluble portion. It is, in fact, in a very large proportion still formative or migratory matter. Hence, too, it is easy to understand how it is, as the results show to be the case, that the percentage of nitrogen in the tubers bears a very direct relation to the supplies available to the plant within the soil.

Leaving the figures relating to the separate periods, the summary at the foot of the Table gives the average results, as to specific gravity and percentage composition, over the total period of twelve years, for the unmanured plot, and for each of the artificially manured plots, and in these the influence of manure on the composition is more directly indicated.

Comparing the first and second columns with one another, it is seen at a glance that there is, with high specific gravity, high percentage of dry matter; and *vice versa*. The produce without manure, and with purely mineral manure, that is to say with the least luxuriance, and consequently the earliest maturity, there is the highest specific gravity, and the highest percentage of dry substance in the tubers. With the nitrogenous manures alone, and very restricted growth, there is lower both specific gravity and percentage of dry matter; and, lastly, with both nitrogenous and mineral manures, and the greatest luxuriance, and imperfect maturity, there is the lowest specific gravity, and the lowest percentage of dry matter in the tubers.

Comparing one plot with another, the percentages of mineral matter and of nitrogen, whether reckoned on the fresh tubers, or on the dry substance, are seen to have no direct relation, either to the specific gravity, or to the percentages of dry matter, but to have a very direct relation to the supplies by manure; and when it is considered how large a proportion of both of these exists in the juice, or, so to speak, in a still formative and comparatively unfixed condition, the fact that their amount in the tubers bears so direct a relation to their supply becomes at once intelligible.

Thus, without manure, there is a comparatively low percentage of mineral matter, and a medium percentage of nitrogen. With mineral manures alone there is the highest percentage of mineral matter, and

by far the lowest percentage of nitrogen. With purely nitrogenous manures there is the lowest percentage of mineral matter, and the highest percentage of nitrogen. Lastly, with both mineral and nitrogenous manures together, there are intermediate percentages, both of mineral matter and of nitrogen, in the tubers.

2.—Farm-yard Manure Series.

TABLE VI.

EXPERIMENTS ON POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Mean percentage Composition of the Good Tubers; 12 years, 1876-1887.

		Specific gravity of the Tubers.	Per cent. in Fresh Tubers.			Per cent. in Dry Matter.	
			Dry Matter.	Mineral Matter (Ash).	Nitrogen.	Mineral Matter (Ash).	Nitrogen.
UNMANURED, 12 YEARS. (Plot 1.)							
Averages	6 years, 1876-1881 ..	1.112	27.74	0.89	0.302	3.23	1.09
	6 years, 1882-1887 ..	1.123	28.44	0.80	0.366	2.81	1.29
	12 years, 1876-1887 ..	1.118	28.09	0.84	0.334	3.02	1.19
FARMYARD MANURE, 6 YEARS; UNMANURED, 6 YEARS. (Plot 2.)							
Averages	6 years, 1876-1881 ..	1.106	25.78	1.00	0.241	3.91	0.93
	6 years, 1882-1887 ..	1.124	28.45	0.86	0.355	3.03	1.25
	12 years, 1876-1887 ..	1.115	27.11	0.93	0.298	3.47	1.09
FARMYARD MANURE AND SUPERPHOSPHATE, 7 YEARS; FARMYARD MANURE ALONE, 5 YEARS. (Plot 3.)							
Averages	6 years, 1876-1881 ..	1.103	25.50	1.04	0.232	4.08	0.91
	6 years, 1882-1887 ..	1.112	26.36	0.96	0.353	3.66	1.35
	12 years, 1876-1887 ..	1.108	25.94	1.00	0.292	3.87	1.13
FARMYARD MANURE, SUPERPHOSPHATE, AND NITRATE OF SODA, 6 YEARS; FARMYARD MANURE ALONE, 6 YEARS. (Plot 4.) (*)							
Averages	6 years, 1876-1881 ..	1.098	24.34	0.93	0.306	3.83	1.26
	6 years, 1882-1887 ..	1.110	25.89	0.94	0.372	3.64	1.44
	12 years, 1876-1887 ..	1.104	25.11	0.93	0.339	3.73	1.35
SUMMARY. AVERAGE 12 YEARS, 1876-1887.							
Unmanured.. .. .		1.118	28.09	0.84	0.334	3.02	1.19
Farmyard Manure, 6 years; Unmanured, 6 years..		1.115	27.11	0.93	0.298	3.47	1.09
Farmyard Manure and Superphosphate, 7 years; Farmyard Manure alone, 5 years		1.108	25.94	1.00	0.292	3.87	1.13
Farmyard Manure, Superphosphate, and Nitrate Soda, 6 years; Farmyard Manure alone, 6 years (*) ..		1.104	25.11	0.93	0.339	3.73	1.35

* The Superphosphate, but not the Nitrate, was applied in the seventh year, 1882.

Reference may be made more briefly to the specific gravity, and to the percentage composition, of the tubers of the farm-yard manure series, as recorded in Table VI. (p. 21).

The Table shows that there was in every case a higher specific gravity, in every case a higher percentage of dry matter, and in every case a lower percentage of mineral matter in the dry substance, over the second period than over the first. All three conditions indicate, therefore, better maturation over the later years.

The percentage of nitrogen is, on the other hand, in every case considerably higher over the second period, with, it will be remembered, lower amounts of crop, dependent partly on lower manuring, and partly on the conditions of season being on the average more favourable for maturation than for luxuriance. That the high percentage of nitrogen over the second period was due to deficient accumulation of starch, as the result of limitation of growth, and not to more total nitrogen being taken up, is obvious from the fact already shown, that there was, in two out of the three cases, less total nitrogen taken up per acre over the second period than over the first.

Owing to the difference in the manuring over the two periods, the average results for the twelve years, as given at the foot of the Table, are not of a very definite character; but they consistently show higher percentages of both mineral matter and of nitrogen, with relatively higher amounts supplied. Especially is the higher percentage of nitrogen very obvious in the produce of the plot to which nitrate of soda was applied during the first six years.

Upon the whole the results which have been given have consistently shown higher specific gravity, and higher percentages of dry matter, the better matured the produce. As between one set of seasons and another, they have also shown lower percentages of mineral matter in the produce of those of the best maturing conditions. But as between one condition of manuring and another, the percentages, both of mineral matter and of nitrogen, have been shown to have a very direct connection with the relative amounts of them supplied within the soil.

It was stated that this fact was no doubt connected with the further fact, that a very large proportion, both of the mineral constituents and of the nitrogen, of the tuber, exists in a still only formative condition in the juice.

Obviously, therefore, it will be of interest to consider such evidence as is at command, as to the comparative composition of the whole tubers, and of the juice, and as to the distribution of the several constituents in the insoluble matter, or so-called *marc*, and in the juice, respectively.

COMPOSITION OF THE WHOLE TUBERS, AND OF THE JUICE.

The upper division of Table VII. (p. 23) shows the percentages of dry matter, of mineral matter (both crude and pure ash), and of nitrogen, in the whole tubers, and in the expressed juice of the tubers,

from each of the ten differently manured plots. The results are, in each case, the averages for the produce of the first three years—1876, 1877, and 1878.

TABLE VII.
EXPERIMENTS ON POTATOES,
Grown year after year on the same land, Hoosfield, Rothamsted.
Composition of the tubers, and of the juice.
Mixed year samples; Seasons, 1876, 1877, and 1878.

		Unmanured.	Superphosphate of Lime.	Mixed Mineral Manure. ()	Ammonium Salts (= 86 lbs. Nitrogen).	Nitrate Soda (= 86 lbs. Nitrogen).	Ammonium Salts and Mixed Mineral Manure.	Nitrate Soda and Mixed Mineral Manure.	Farmyard Manure.			Means.
									Alone.	And Superphosphate.	Superphosphate and Nitrate Soda.	
PERCENTAGE COMPOSITION OF THE TUBERS AND OF THE JUICE.												
Dry Matter ...	{ Tubers	27.6	24.7	24.5	23.0	24.5	24.3	24.5	24.8	24.4	23.4	24.6
	{ Juice	4.6	4.7	4.6	4.7	4.9	4.8	5.1	4.5	4.6	4.9	4.7
Ash (Crude) ...	{ Tubers	0.91	1.14	1.14	0.75	0.73	1.10	1.07	1.01	1.05	0.95	0.99
	{ Juice	1.10	1.38	1.39	0.93	0.87	1.26	1.28	1.21	1.23	1.13	1.18
Ash (Pure) ...	{ Tubers	0.90	1.13	1.13	0.74	0.71	1.07	1.05	0.99	1.03	0.93	0.97
	{ Juice	1.08	1.37	1.38	0.93	0.87	1.26	1.27	1.21	1.22	1.12	1.17
Nitrogen ..	{ Tubers	0.27	0.19	0.18	0.31	0.32	0.25	0.26	0.22	0.20	0.29	0.25
	{ Juice	0.27	0.22	0.21	0.36	0.38	0.27	0.29	0.24	0.23	0.33	0.28
PERCENTAGE COMPOSITION OF THE PURE ASH.												
Ferric oxide and Alumina ...	{ Tubers	0.40	0.30	0.32	0.50	0.56	0.43	0.37	0.35	0.37	0.41	0.40
	{ Juice	0.50	0.53	0.51	0.44	0.49	0.37	0.51	0.51	0.46	0.56	0.49
Lime ...	{ Tubers	2.16	1.55	1.56	2.77	2.42	1.64	1.50	1.53	1.45	1.63	1.82
	{ Juice	2.27	1.67	1.94	2.26	2.27	1.81	1.75	1.67	1.56	1.74	1.89
Magnesia ...	{ Tubers	3.62	3.37	3.45	3.17	3.85	3.54	3.92	3.48	3.31	3.72	3.54
	{ Juice	4.32	3.76	3.80	3.55	4.17	3.86	4.42	3.91	3.67	4.16	3.96
Potash ...	{ Tubers	55.94	58.52	58.21	55.54	53.87	58.79	58.21	58.27	58.52	57.59	57.35
	{ Juice	53.42	57.92	57.08	55.53	54.02	56.89	57.31	56.81	57.39	56.00	56.24
Soda ..	{ Tubers	0.19	0.32	0.53	0.19	2.89	0.02	0.69	0.06	0.12	0.78	0.58
	{ Juice	1.77	0.37	0.57	0.49	2.00	0.49	0.74	0.52	0.49	1.21	0.87
Phosphoric Acid {	Tubers	14.83	13.00	12.86	12.20	13.08	11.19	11.96	12.86	12.14	12.35	12.64
	{ Juice	11.12	10.87	10.27	9.33	10.21	8.90	9.46	10.11	9.35	9.73	9.93
Sulphuric Acid {	Tubers	8.77	5.72	6.21	8.31	7.35	5.53	5.89	5.87	5.95	6.20	6.58
	{ Juice	9.99	6.91	7.23	9.54	8.86	6.78	7.45	6.91	6.72	7.07	7.75
Chlorine ...	{ Tubers	5.37	4.76	4.79	9.53	4.28	7.34	2.84	7.27	8.05	4.76	5.90
	{ Juice	5.42	5.43	5.60	11.65	6.35	7.46	3.22	8.73	9.08	5.36	6.83
Carbonic Acid...	{ Tubers	9.25	13.03	12.58	9.05	11.88	12.53	14.75	11.87	11.31	13.07	11.88
	{ Juice	12.16	13.63	14.17	9.67	12.90	15.02	15.77	12.69	13.23	15.27	13.45
Silica ...	{ Tubers	0.68	0.50	0.57	0.89	0.83	0.64	0.51	0.58	0.60	0.57	0.64
	{ Juice	0.25	0.13	0.09	0.16	0.16	0.11	0.09	0.11	0.10	0.11	0.13

(*) Superphosphate, and Sulphates of Potash, Soda, and Magnesia.

The lower division of the Table shows the percentage composition of the pure ash, of the tubers, and of the juice, respectively; propor-

tionally mixed samples of the ashes of the three years having been, in each case, made and analysed. The analyses were made by Mr. R. Richter, of Berlin.

The first three columns of the Table relate to the plots without nitrogenous manures—that is without any manure, with superphosphate alone, and with mixed mineral manure alone; the next four columns to the plots with artificial nitrogenous manures, without and with mineral manure in addition; and the last three to those with farm-yard manure.

It is seen in the upper division of the Table, that the percentage of dry substance in the tubers ranges from 27·6 per cent. in the unmanured produce, to only 23 per cent. with ammonium salts alone.

The percentage of dry matter in the expressed juice, ranges from 5·1 in that of the tubers grown by mixed mineral manure and nitrate of soda, and 4·9 in that of those by nitrate of soda alone, or nitrate of soda added to farm-yard manure—these being the conditions of the greatest luxuriance of growth—to 4·5 with farm-yard manure alone, 4·6 without manure, with the mixed mineral manure alone, and with farm-yard manure and superphosphate—these being conditions of comparatively early maturity. There is thus indication that the juice remains the richer the less matured the crop; in other words, that the juice includes a good deal of not finally fixed matter, which is, in fact, material for further maturation; or, like the starch itself, for the nutriment of the plant which would in natural course be grown from the tuber. It may here be stated that the juice, which shows the percentage composition recorded in the Table, generally constitutes not far from 80 per cent. of the fresh tubers.

Although the percentage of dry matter in the fresh juice ranges only about one-fifth as high as that in the fresh tubers, the lines recording the percentages of pure ash, uniformly show a higher percentage of it, that is of mineral matter, in the fresh juice than in the fresh tubers. This of course implies that there is a much lower percentage of mineral matter in the insoluble substance than in the juice. Indeed it will be seen further on that perhaps 85 per cent., or even more, of the total mineral constituents of the tubers, may exist in the juice. Then, again, there is a wide range of variation in the percentage of mineral matter, both in the fresh tubers, and in the fresh juice, according to the conditions of manuring; the variations in the case of the whole tubers being mainly due to those in the juice. We have in these facts further evidence of the less fixed condition of the constituents of the juice, and of the less essential occurrence of a considerable proportion of them.

Next as to the percentage of nitrogen: it is seen to range from 0·18 in the fresh tubers grown by mixed mineral manure alone, to nearly double, or 0·31 and 0·32 in those grown by nitrogenous manure alone. In the same cases it ranges in the fresh juice from 0·21 to 0·36 and 0·38; and when it is borne in mind that from 80 to 85 per cent. of the total nitrogen of the tubers may exist in the juice, it is obvious that the range of variation in its amount in the insoluble matter is comparatively

limited. Further illustrations will be given on this point presently.

Referring to the lower division of the Table, the last column shows, for the ten different conditions as to manuring, the average percentage of each of the mineral constituents in the ash of the whole tubers, and in that of the juice. It is remarkable how nearly identical is the percentage composition of the two descriptions of ash, and this fact indicates much more of selective action, and of essentialness of composition, in the juice, than is generally found in the more purely vegetative organs of plants—such as the leaves and stems. But, in judging of the significance of the figures, it has to be borne in mind that the ash of the juice which shows this percentage composition may constitute 80 to 85 per cent., or even more, of the total ash of the tubers—a fact, the bearing of which will be illustrated further on.

I will not refer to much of the detail given in the other columns. It will suffice to call attention to the variations in the percentages of some of the more important constituents—potash and phosphoric acid for example—according to the conditions of manuring.

Thus it is seen that the percentage of potash ranges relatively high where the supply of it is relatively liberal, as for instance with the purely mineral manures, with the farm-yard manure, and with the nitrogenous and mixed mineral manures together. It is, on the other hand, relatively low without manure, and with the purely nitrogenous manures. Further, there is generally a somewhat corresponding tendency in the percentage in the ash of the juice, and in that of the whole tubers, a large proportion of the latter consisting of that of the former. Then it is to be observed, that where there was deficiency of potash in the supply, and in the ash, there is generally an increased percentage of lime in the ash, doubtless derived from the resources of the soil itself.

Next as to the phosphoric acid, its percentage is not so uniform as that of the potash. It is, under every condition of manuring, higher in the ash of the whole tuber than in that of the juice. On the other hand, the percentage of sulphuric acid is, in every case, higher in the ash of the juice than in that of the whole tubers. Lastly, in the ash both of the tubers and of the juice, when there is relatively high percentage of phosphoric acid, there is a general but not a uniform tendency to a relatively low percentage of sulphuric acid, and *vice versâ*.

Referring to the less essential constituents of the fixed formations, such as soda and chlorine for example, it may be observed that their percentage varies considerably, and is apparently very dependent on the supply within the soil.

CONDITIONS OF COMBINATION OF THE NITROGEN OF THE POTATO;
AND THE DISTRIBUTION OF THE NITROGENOUS
CONSTITUENTS IN THE SOLID MATTER, AND IN THE JUICE.

I now come to the very important question of the condition of combination of the nitrogen of potato tubers, and of the distribution of

the nitrogenous compounds, in the solid matter, and in the juice.

Table VIII. (below) shows the proportion of the total nitrogen of the tubers which exists as albuminoid or flesh-forming compounds, and the proportion which is in other forms. It also shows the proportion of the albuminoids which exist in the insoluble condition in the marc, and in the soluble condition in the juice. The upper division of the Table gives some results of *E. Schulze*, and the lower division results obtained at Rothamsted, on these points.

TABLE VIII.

Proportion of Albuminoid Nitrogen, and Non-Albuminoid Nitrogen, in Potatoes.

					Per cent. of the Total Nitrogen of the Tubers—			
					Albuminoid.			Non- Albu- minoid (*)
					In Marc.	In Juice.	Total.	
E. SCHULZE'S RESULTS.								
No. 1					Per cent.	Per cent.	Per cent.	Per cent.
No. 2					19.8	41.0	60.8	39.2
No. 3					13.5	46.2	59.7	40.3
No. 4					20.0	27.4	47.4	52.6
No. 5					14.0	34.2	48.2	51.8
No. 5					24.2	40.8	65.0	35.0
Mean					18.3	37.9	56.2	43.8
ROTHAMSTED RESULTS, 1878.								
Unmanured					15.8	48.7	64.5	35.5
Superphosphate					9.1	57.6	66.7	33.3
Mixed Mineral Manure					14.4	57.5	71.9	28.1
Ammonium Salts					12.3	45.1	57.4	42.6
Nitrate of Soda					11.0	40.8	51.8	48.2
Ammonium Salts and Mixed Mineral Manure ..					16.1	47.6	63.7	36.3
Nitrate of Soda and Mixed Mineral Manure ..					17.1	46.9	64.0	36.0
Farmyard Manure					22.0	45.9	67.9	32.1
Farmyard Manure and Superphosphate					19.5	49.8	69.3	30.7
Farmyard Manure, Superphosphate, and Nitrate of Soda					12.6	46.5	59.1	40.9
Mean					15.0	48.6	63.6	36.4

(*) Chiefly Amide.

It is seen that, of the total nitrogen of the tubers, Schulze found the amount existing as albuminoids in the insoluble matter to range from 13.5 to nearly double, or 24.2 per cent. of the whole, and to average only 18.3 per cent. In other words, on the average of the five experiments, 81.7 per cent. of the total nitrogen of the tubers existed in the juice.

In the Rothamsted experiments there was probably much greater variation in the conditions and characters of growth, than in those of Schulze; and we find a variation in the amount of the total nitrogen.

of the tubers existing as albuminoids in the solid matter, from 9.1 to 22.0 per cent. of the whole; and the average to be only 15 per cent. The tendency of error of analysis would probably be to show too low an amount of the total nitrogen in the marc. However, the two sets of results sufficiently agree with one another to establish the fact that probably as a rule less than 20 per cent. of the total nitrogen will exist as insoluble albuminoids.

But the average of Schulze's results shows 37.9, and the average of the Rothamsted results 48.6 per cent. of the total nitrogen of the tubers, to exist as soluble albuminoids in the juice. In solid matter and juice together, therefore, Schulze's results show an average of 56.2 per cent., and those of Rothamsted of 63.6 per cent., of the total nitrogen of the tubers to exist as albuminoids; though from two-thirds to three-fourths of this may be in the juice.

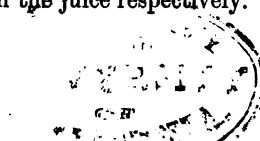
On the other hand, Schulze's results show an average of 43.8, and those of Rothamsted of 36.4 per cent., of the total nitrogen of the tubers, to be in a non-albuminoid condition. By far the larger proportion of this non-albuminoid nitrogenous matter exists as amides, and much less as ammonia or nitric acid than is usual in the case of root-crops. The nutritive value of the non-albuminoid nitrogenous matters, which it is seen may amount to from one-third to perhaps nearly half of the total nitrogen of the tubers, is, however, to say the least, doubtful. Further, as two or three times as much of the albuminoid matter itself exists in the juice as in the insoluble portion of the tubers, it is probable that a considerable proportion, even of the albuminoid substance, will be lost as food. To this point I shall recur presently.

DISTRIBUTION OF THE CONSTITUENTS IN 1000 PARTS OF FRESH TUBERS.

It will be well now, disregarding the variations that may occur dependent on different conditions as to soil, season, manuring, and other circumstances, to endeavour to form a judgment as to the probable or approximate average composition of Potato tubers. Accordingly, Table IX. (p. 28) gives the estimated average composition of 1000 parts of fresh Potato tubers, and shows the probable distribution of the constituents, in the insoluble matter, and in the juice, respectively. The estimates are founded mainly on the average composition of the whole tubers, and of the juice, of the produce of the ten plots, over the first three seasons, 1876, 1877, and 1878, but partly also on other Rothamsted results, and on those of other experimenters.

The first column shows the estimated amounts of dry matter, nitrogen, total mineral matter (or ash), and of each ash-constituent, in 1000 of fresh tubers. The second and third columns show the distribution of the several constituents in the marc, and in the juice, respectively, of 1000 parts of the tubers.

The last two columns show, for 100 of dry matter, of nitrogen, and of ash, the proportion of each in the marc, and in the juice respectively.



They also show, for 100 of total ash in the tubers, the amount of each ash-constituent in the marc, and in the juice.

TABLE IX.
EXPERIMENTS ON POTATOES.

Hoosfield, Rothamsted.

Estimated average distribution of the constituents in 1000 parts of Fresh Tubers.

Constituents.	In Tubers.	In Marc.	In Juice.	Per cent. of total.	
				In Marc.	In Juice.
Dry Matter	246	209	37	85.0	15.0
Nitrogen	2.5	0.4	2.1	15.0	85.0
Ash { Crude	9.9	1.5	8.4	15.0	85.0
{ Pure	9.7	1.4	8.3	15.0	85.0
Ferric oxide and Alumina ..	0.04	0.00	0.04	0.00	0.41
Lime	0.18	0.02	0.16	0.21	1.63
Magnesia	0.35	0.02	0.33	0.21	3.36
Potash	5.58	0.88	4.70	9.43	47.90
Soda	0.06	(-0.01)	0.07	(-0.11)	0.71
Phosphoric Acid	1.23	0.40	0.83	4.29	8.46
Sulphuric Acid	0.64	0.00	0.64	0.00	6.52
Chlorine	0.57	0.00	0.57	0.00	5.81
Carbonic Acid	1.16	0.04	1.12	0.43	11.42
Silica	0.06	0.05	0.01	0.54	0.10
Total	9.87	1.40	8.47	15.00	86.32
Deduct O = Cl.	0.13	0.00	0.13	0.00	1.32
Total	9.74	1.40	8.34	15.00	85.00

Directing attention first to the four upper lines of the Table, it is seen that 1000 parts of fresh Potato tubers are estimated to contain, on the average, 246 parts (or 24.6 per cent.) of total dry substance; 209 of which will be in the marc, and 37 in the juice. These amounts represent, as the last two columns of the Table show, 85 per cent. of the total solid matter to be in the marc, and 15 per cent. to be in the juice.

The amount and the distribution of the nitrogen is next shown. 1000 parts of the fresh tubers are estimated to contain 2.5 parts of nitrogen, or 0.25 per cent. Of this 2.5 parts, only 0.4 parts are estimated to be contained in the insoluble matter, and 2.1 parts in the juice. In other words, as the last two columns show, only about 15 per cent. of the total nitrogen of the tubers are supposed to be in the insoluble matter, and 85 per cent. in the juice.

The next two lines relate to the amount, and the distribution, of the mineral or ash constituents; the first of the two represents the amounts of crude ash as incinerated, and the second the amounts of pure ash, that is excluding any adventitious matter, such as sand and charcoal. As the individual mineral constituents are reckoned on the amount of pure ash, attention may be confined to the amount and distribution of it.

1000 parts of fresh tubers are estimated to contain 9·7 parts, or nearly 1 per cent. of pure ash. Of this, only 1·4 parts are supposed to be in the insoluble matter, and 8·3 parts in the juice—amounts corresponding to only 15 per cent. of the total pure ash in the insoluble matter, and 85 per cent. in the juice.

Thus, whilst of the total dry substance of the tubers 85 per cent. is reckoned to be in the insoluble matter, and only 15 per cent. in the juice; of the total nitrogen, and of the total mineral matter, only 15 per cent. is reckoned to be in the insoluble matter, and 85 per cent. in the juice.

Attention must now be briefly directed to the amount and the distribution of the individual mineral constituents in 1000 parts of the fresh tubers, as shown in the lower portion of the Table.

The ferric oxide and alumina are found in immaterial amount, and are probably mainly to be attributed to traces of adherent soil, not removed from the tubers in washing.

The lime, the soda, and the silica, are also in immaterial amounts, and the quantity of magnesia is also comparatively small. As already pointed out, the quantity of chlorine is very variable, and mainly dependent on the amount of the supply, whilst its occurrence is probably connected with its agency as a carrier of other constituents, rather than as an essential constituent in connection with any special function of the plant. Then there is the carbonic acid, which is probably in great part, the product of the destruction of organic acid in the incineration.

There remain the potash, the phosphoric acid, and, in a less degree, the sulphuric acid, as prominent mineral constituents of the tubers.

The Table shows that 1000 parts of the fresh tubers are reckoned to contain 5·58 parts of potash, 1·23 parts of phosphoric acid, and 0·64 parts of sulphuric acid.

It has been stated that potash is essentially connected with the formation of starch, and other non-nitrogenous matters, and phosphoric acid, and in some degree sulphuric acid, with that of the nitrogenous compounds. Yet we see that, of the 5·58 parts of potash in 1000 parts of tubers, only 0·88 parts exist in the marc, and 4·7 parts in the juice. A portion of that in the juice may, of course, be surplusage considered in relation to the transformations with which it is connected. But the fact that a much larger amount of the potash remains in the juice unassociated with the already formed and stored up starch, is of itself no evidence that it has not been of avail in the changes necessary to its formation; and the fact that the percentages of potash and phosphoric acid, and even of sulphuric acid, are so comparatively uniform in the ashes of the total tubers, and in those of the juice, and that they vary so little under such very various conditions of manuring, that is of their supply, would indicate that the amounts have some direct relation to the physiological changes within the organ, essential to its special formations.

Turning to the phosphoric acid, it is seen that of the 1·23 parts in

1000 of fresh tubers, 0.40 are reckoned to be in the marc, and 0.83 in the juice; or almost exactly one-third in the marc, and two-thirds in the juice. That there should be a considerable proportion of the whole of the phosphoric acid in the juice, seems quite consistent with the fact that so large a proportion of the albuminoid compounds exists in the juice. Indeed the average of Schulze's analyses shows almost exactly the same proportion of the total albuminoids to be in the juice—namely about two-thirds—as the estimates now under consideration show to be the case with the phosphoric acid.

Of the 0.64 parts of sulphuric acid in 1000 of fresh tubers, practically the whole is found in the juice.

The general conclusion to which these calculations as to the distribution of the various constituents of Potato tubers leads is—that from 80 to 85 per cent., or even more, of the total nitrogen of the tubers may be in the juice, and that about the same proportion of the total mineral matter also, may be in the juice. Further, that about the same proportion—80 to 85 per cent.—of the total potash, and about two-thirds of the total phosphoric acid, are in the juice. And when it is borne in mind that two-thirds, or more, of the nitrogen existing as albuminoids is in the juice, it is obvious that if the mode of cooking the Potato is such as to exclude the constituents of the juice from the final food product, there is considerable waste of nutritive matter; and that, indeed, the proportion of albuminoid matter in the food is exceedingly small. When Potatoes are used as a mere adjunct to an otherwise liberal diet, the general practice is to cut off the rind, and to put the peeled Potatoes into cold water, by which a large proportion of the soluble albuminoid matters must be washed out, before the temperature of the water becomes sufficiently high to coagulate and fix them. A very large proportion of the potash must also be washed out under such circumstances. When, however, potatoes constitute an important item in the diet, as in the rural districts of Ireland for example, it is usual to boil them in their skins—or, as is said, in their jackets. Under such circumstances, certainly a much larger proportion of the albuminoid matter will reach the stomachs of the consumers; and doubtless much more of the potash and phosphoric acid also. Still, it is obvious that a Potato diet must be very deficient in the proportion of nutritive nitrogenous compounds.

INCREASED PRODUCTION OF STARCH BY NITROGENOUS MANURES.

But although only about 15 per cent. of the total nitrogenous compounds of the tuber exists in the insoluble matter, and a very large proportion of the remainder—greater or less according to circumstances—is not available as flesh-forming material, yet Table IX. shows that 85 per cent. of the total dry or solid matter of the tuber may be in the insoluble matter or marc. The next question to consider is, therefore, of what does this consist? It has been incidentally stated that it consists chiefly of the non-nitrogenous substance—starch. It has further been

stated that the amount of starch may approximately be estimated from the specific gravity of the tubers, or from their percentage of dry substance. It has also been assumed that the increased amount of dry matter grown, per acre, under the influence of nitrogenous manures, consisted mainly of this non-nitrogenous substance. These various points are illustrated by the figures in the following Table (X).

TABLE X.
EXPERIMENTS ON POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Estimates of Increase of Starch produced by Nitrogen in Manure. Average of 10 years, 1876-1885.
(Approximate Estimates.)

	Specific gravity of Tubers.	Dry Matter.		Estimated per cent. in Tubers.	Starch.					
		Per cent. in Tubers.	Per Acre.		Per acre.			For 1 Nitrogen in Manure.		
					In Produce.	In increase over Unmanured.	In increase over Mixed Mineral Manure.	In increase over Unmanured.	In increase over Mixed Mineral Manure.	
Unmanured	1.116	p. c. 28.0	lbs. 1353	p. c. 23.2	lbs. 1120					
Mixed Mineral Manure	1.113	26.2	2384	21.9	1988					
Ammonium Salts... ..	1.108	25.8	1419	21.4	1169	49		0.6		
Nitrate of Soda	1.111	26.2	1649	21.7	1362	242		2.8		
Mixed Mineral Manure and Ammonium Salts	1.103	25.3	4121	21.1	3436	2316	1448	26.9	16.8	
Mixed Mineral Manure and Nitrate of Soda	1.107	25.5	4069	21.2	3368	2248	1380	26.1	16.1	

The Table shows, for the tubers grown without manure, and with the mixed mineral manure alone, with the nitrogenous manures alone, and the mixtures of mineral and nitrogenous manures, the average specific gravity over the ten years, 1876 to 1885, the average percentage of dry matter in the tubers, and total dry matter produced per acre. Next is shown the estimated percentage of starch in the tubers, calculated from the percentage of dry matter, by a factor arrived at by a consideration both of the rules of estimate of others, and of the results of calculations at Rothamsted, eliminating the other constituents.

As already fully illustrated, it is seen that high specific gravity of the tubers and high percentage of dry matter go together. The total amount of dry matter produced per acre, is considerably increased by the mineral manure alone, but very much more when the mineral and nitrogenous manures are used together. Thus, the produce of dry substance of tubers was, without manure 1353 lbs. per acre; with purely mineral manure 2384 lbs.; and with the mixture of the mineral and nitrogenous manures more than 4000 lbs. per acre.

The remaining columns show, the estimated percentage of starch in the tubers, the calculated total amounts of it per acre on the different plots, the increased amounts per acre over the amount without manure, under the influence of the nitrogenous manures, both when used alone, and in conjunction with the mineral manures; also the increased amounts over the produce with purely mineral manures, when both mineral and nitrogenous manures are used together. Finally, there is shown the increased amounts of starch produced by the use of 1 part of nitrogen in manure, reckoned both over the unmanured, and over the mineral manured produce.

It will be observed that the Potatoes are reckoned to contain on an average more than 21 per cent. of starch.

The produce of starch per acre is 1120 lbs. without manure, and 1988 or nearly 2000 lbs. with purely mineral manure—that is without nitrogen. The amount with purely nitrogenous manure is not so great as that with purely mineral manure. But with both nitrogenous and mineral manure, the quantity of starch is raised to an average of about 3400 lbs., or about $1\frac{1}{2}$ ton per acre.

The increased amount of starch over that without manure, produced by nitrogenous manures alone, containing 86 lbs. of nitrogen, is very small; only 49 lbs. when as ammonium salts; and 242 lbs. when as nitrate of soda. When both nitrogenous and mineral manures are used together, the increased amount of starch produced is more than 1 ton per acre—2316 lbs. with ammonium salts, and 2248 lbs. with nitrate of soda; but the increased amounts reckoned over the produce by the purely mineral manure, are only about two-thirds as much as when reckoned over the unmanured yield—namely, 1448 and 1380 lbs.

The last two columns show the increased amount of starch obtained for 1 of nitrogen supplied in the manure.

With the purely nitrogenous manures there is practically no increase in the amount of starch produced. When the two descriptions of manure are used together, there is, for 1 of nitrogen in manure, 26.9 and 26.1 parts, increased produce of starch reckoned over the unmanured produce, and 16.8 and 16.1 parts reckoned over the produce by the mixed mineral manure alone.

Here, then, in the Potato, we have a great increase in the production of the non-nitrogenous constituent—*starch*, by the use of nitrogen in manure, just as in the root-crops we have a great increase in the produce of the non-nitrogenous constituent—*sugar*, by the use of nitrogenous manure. There is, however, under corresponding conditions as to manure, somewhat more sugar produced in Mangel Wurzel for 1 of nitrogen in manure, than of starch in the Potato. Thus, with similar mineral manures, and the same amounts of nitrogen supplied, we had, reckoned over the produce by the mineral manures alone, in Mangel Wurzel 19.0 parts of sugar for 1 of nitrogen as ammonium salts, against 16.8 parts of starch in the Potato; and for 1 of nitrogen as nitrate of soda, we had 22.1 parts of sugar produced in the Mangel Wurzel, and 16.1 parts of starch in the Potato.

In the sugar-beet, however, there was even much more sugar produced for 1 of nitrogen—namely, when as ammonium-salts 28·6 parts, and when as nitrate of soda 36·0 parts.

As then the root-crops are essentially sugar-yielding crops, so the Potato is essentially a starch-yielding crop; and it is seen that, provided the mineral constituents are not deficient, the produce of both sugar and starch is greatly increased by the amount of nitrogen available to the plant within the soil, whether derived from previous accumulations, or from direct nitrogenous manuring.

This result, the greatly increased production of non-nitrogenous substances, by the use of nitrogenous manures, is equally striking in the case of cereal crops. The most prominent effect of the use of nitrogenous manures to such crops, is the increased production of starch in the grain, and of cellulose in the straw. Indeed, it is chiefly for the increased production of the non-nitrogenous substances, starch, sugar, and cellulose, that our direct nitrogenous manures are used. And if we reckon, not the amount of nitrogen applied, but only the increased amount of it taken up by the growing vegetation, it is obvious that the amounts of non-nitrogenous substances produced for 1 of nitrogen so taken up, are very much greater than the estimates above referred to would indicate.

In my lecture last year, I showed how small was the proportion of the flesh-forming nitrogenous constituents, to the non-nitrogenous or specially respiratory and fat-forming constituents, in root-crops; and in the Potato the proportion is considerably smaller still. For whilst the percentage of total nitrogen is much the same in fresh Mangel Wurzel, or Swedish Turnips, as in fresh Potatoes, the fresh tuber contains twice, or more than twice, as much digestible non-nitrogenous matter as the roots. On the other hand, a larger proportion of the total nitrogen exists as albuminoid compounds in the Potatoes than in the root-crops.

CONDITIONS OF SEASON AND MANURING FAVOURING DISEASE.

Thus far I have treated of the conditions of growth, and of the composition, of Potato tubers; and it has been shown that both the growth and the composition are very characteristically influenced both by season and manuring, and, so far as manure is concerned, very specially by nitrogenous manures. Incidentally it has been shown that both the occurrence, and the development, of the disease are also very materially influenced by both season and manuring.

The well known fact that the characters of the season have much to do with the development of the disease was very conclusively borne out by the results adduced. It was seen that under every condition as to manuring, whether artificial or otherwise, there was, on the average, a very much larger proportion of diseased tubers over the first four, or generally wetter seasons, when moreover the "Rock" was grown, than over the subsequent seasons of, on the average, better maturing

conditions, but when also the "Champion" was grown. It is not without interest to observe, that there was such a very great reduction in the amount of disease over the later periods of the continuous growth of the crop on the same land; conditions which might be considered unfavourable for healthy growth. It should be stated, however, that every year fresh seed was procured from a distance.

Then, again, so far as the influence of manuring is concerned, it was seen that the proportion of diseased tubers was the least where there was no supply of nitrogen by manure; that is where there was the least luxuriance, and the most restricted growth, and with this, the ripening tendency early developed. On the other hand, it was where there was liberal supply of nitrogen, and the most luxuriant growth, that there was by far the greatest proportion of diseased tubers.

It is not within my province, nor am I competent, to pass any judgment on either the admitted, or the disputed points relating to the identity, the morphological characters, and the mode of development, of the fungus. But the investigations carried on at Rothamsted do throw some light on the conditions, both without and within the plant, under which the development of the fungus is the most favoured, and on the results of its growth on the chemical composition of the tubers.

The fact that wet seasons favour the development of the disease would seem, independently of any influence favouring the migration of the spores, to be largely dependent on the condition of succulence and activity engendered in the juice; and the fact that there is much less disease with restricted growth, and early ripening, may simply mean that, under such conditions of the tuber, there is in the juice a restricted supply of food for the fungus. At any rate it is under the contrary conditions—those in which the juice is relatively rich in nitrogenous and mineral matters—that the development of the disease is the most pronounced. It has to be borne in mind that, in the experiments under consideration, the occurrence of the meteorological conditions favouring the development of the disease, finds the tubers of the different plots in very different conditions, not only as to richness of juice due to supply by manure, but, owing to these very conditions, in very different states as to maturity, that is as to fixity of composition, or susceptibility to change. The question arises, therefore, how far the tubers of restricted development, and greater maturity, would have shown more susceptibility to the disease if the adverse meteorological conditions had prevailed at an earlier stage of their growth; or how far, if they had occurred later, the more luxuriant tubers would have suffered less. However this may be, certain it is that, when the unsuitable weather comes, those tubers suffer most which have the richest juice, and the least fixity of composition.

CHEMICAL CHANGES IN THE TUBERS, INDUCED BY THE DISEASE.

I now come to the question—what are the changes which the development of the disease induces in the chemical composition of the

tubers? We have only been able to devote attention to this subject in certain special and limited aspects, but the results which have been obtained are consistent and definite, so far as they go, and of considerable interest.

In the first place, the percentages of dry matter, mineral matter, and nitrogen, were determined in the good or well-grown tubers, in the small or imperfectly developed tubers, and in the diseased tubers, of most of the experimental plots, in each of the first three years of the experiments. The sugar was also determined by the polariscope, in the juice of the good and of the small Potatoes.

Next, in a considerable number of cases, the white and the dark portions of diseased Potatoes were carefully separated. Each of these was separately pressed, so as to obtain the juice, and the insoluble portion or marc, separately, for analysis. In the juice of each, the mineral matter and the nitrogen were determined. In all cases the sugar, by polariscope, was determined; and, in selected cases, the glucose already existing, and the total sugar in the juice, after conversion into glucose. Lastly, in the marc, both of the white and of the dark portions, the mineral matter, and in some cases the nitrogen, was determined.

The data were thus provided, in the first place for comparing the composition, in some important aspects, of the fully matured, of the immature, and of the diseased, whole tubers; also for the comparison of the composition of the insoluble portion, and of the juice, both of the white or incipiently diseased, and of the dark or fully diseased, portions of the diseased tubers.

Table XI. (p 36) shows the percentages of dry matter, mineral matter, and in many cases of nitrogen in the dry matter, of the good, the small, and the diseased whole tubers, from each of the ten differently manured plots, in each of the first three years of the experiments—1876, 1877, and 1878. It also shows, in each case, the percentage of sugar, as determined by the polariscope, in the juice of the good, and of the small Potatoes.

I do not propose to refer in detail to the results relating to the produce of individual plots, but only to call attention to the general and average character of the results.

Referring first to the percentages of dry matter, a glance at the columns shows that, in every case but one in 1876, in eight out of the ten cases in 1877, and in nine out of ten in 1878, there was a lower percentage of dry substance in the less developed small, than in the more matured, or so designated "good" tubers. Again, there was, over the three years, in every case but one, a considerably lower percentage of dry matter in the diseased than in either the good or the small Potatoes. This result must obviously be due either to acquisition of water, or to loss of dry or solid substance, under the influence of the disease.

The next columns, which show the percentages of mineral matter in the dry substance of the different descriptions of tuber, afford satisfactory evidence that there had been a considerable loss of solid organic substance.

TABLE XI.

EXPERIMENTS ON POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Particulars of the Composition of the Good, Small, and Diseased Potatoes.

	Per cent. in Tubers.									Per cent. in Juice.	
	Dry Matter.			Mineral Matter in Dry.			Nitrogen in Dry.			Sugar by Polariscopes.	
	Good.	Small.	Diseased.	Good.	Small.	Diseased.	Good.	Small.	Diseased.	Good.	Small.
FIRST SEASON, 1876.											
Unmanured	p. c. 33.87	p. c. 23.65	p. c. 20.22	p. c. 3.53	p. c. 3.49	p. c. 4.27	p. c. 1.196	p. c. 1.113	p. c. 1.268	p. c. 0.60	p. c. 0.76
Superphosphate	23.50	22.85	18.42	4.72	4.86	5.73	0.844	0.961	1.622	0.43	0.57
Mixed Mineral Manure (*)	22.89	21.28	20.73	4.64	4.94	5.21	0.744	0.962	0.988	0.43	0.59
Ammonium Salts	22.10	22.29	18.62	3.67	3.70	5.24	1.501	1.493	1.855	0.48	0.55
Nitrate of Soda	22.00	21.49	19.00	3.59	3.84	4.48	1.486	1.510	1.784	0.46	0.60
Ammonium Salts and Mixed Mineral Manure	20.87	19.49	18.02	4.71	5.01	5.96	1.274	1.510	1.808	0.52	0.57
Nitrate of Soda and Mixed Mineral Manure	21.89	20.47	19.36	4.46	4.76	5.39	1.332	1.573	1.593	0.48	0.58
Farmyard Manure	22.42	22.01	20.78	4.11	4.20	4.64	0.954	1.026	1.118	0.57	0.69
Farmyard Manure and Superphosphate	23.45	22.32	20.46	4.27	4.56	5.01	0.814	1.010	1.110	0.58	0.62
Farmyard Manure, Superphosphate, and Nitrate of Soda	21.23	20.64	17.91	3.92	4.12	5.24	1.890	1.497	1.722	0.40	0.53
Mean	22.52	21.65	19.35	4.16	4.35	5.11	1.147	1.266	1.486	0.50	0.61
SECOND SEASON, 1877.											
Unmanured	33.03	27.47	25.01	3.17	3.28	3.61	0.914			0.49	0.97
Superphosphate	26.53	25.76	23.54	4.44	4.68	5.11	0.784			0.27	0.54
Mixed Mineral Manure (*)	26.76	24.64	22.79	4.52	4.85	5.35	0.778			0.25	0.37
Ammonium Salts	21.99	25.72	22.62	3.07	3.18	3.74	1.276			0.61	0.89
Nitrate of Soda	25.86	26.80	22.90	2.85	3.00	3.56	1.164			0.63	0.80
Ammonium Salts and Mixed Mineral Manure	28.44	23.72	22.20	4.33	4.90	5.63	0.951			0.23	0.47
Nitrate of Soda and Mixed Mineral Manure	27.27	24.36	22.89	4.26	4.85	5.49	0.981			0.49	0.50
Farmyard Manure	26.49	24.45	21.39	4.00	4.22	5.33	0.900			0.33	0.62
Farmyard Manure and Superphosphate	25.96	24.35	20.50	4.26	4.49	5.90	0.799			0.30	0.55
Farmyard Manure, Superphosphate, and Nitrate of Soda	27.21	24.25	23.10	3.90	4.14	5.04	1.107			0.29	0.63
Mean	26.95	25.15	22.63	3.88	4.16	4.88	0.953			0.39	0.63
THIRD SEASON, 1878.											
Unmanured	25.96	24.25	21.62	3.26	3.93	4.43	0.878			1.82	1.92
Superphosphate	24.08	22.90	19.86	4.74	5.28	6.93	0.684			1.42	1.30
Mixed Mineral Manure (*)	23.68	22.76	20.58	4.90	5.36	6.37	0.706			1.44	1.23
Ammonium Salts	24.38	24.10	19.64	3.12	3.26	4.15	1.246			1.57	1.42
Nitrate of Soda	25.47	23.93	21.56	2.64	3.37	3.41	1.281			1.60	1.88
Ammonium Salts and Mixed Mineral Manure	23.55	20.93	19.11	4.57	5.25	6.25	0.946			1.27	1.00
Nitrate of Soda and Mixed Mineral Manure	24.42	21.69	20.44	4.41	5.45	5.93	0.935			1.25	1.17
Farmyard Manure	24.36	22.48	20.39	4.20	5.05	5.21	0.857			1.20	1.38
Farmyard Manure and Superphosphate	23.76	22.11	18.22	4.35	5.05	5.92	0.864			1.29	1.77
Farmyard Manure, Superphosphate, and Nitrate of Soda	21.86	22.22	18.78	4.45	5.12	5.30	1.229			1.23	1.50
Mean	24.20	22.74	20.02	4.06	4.71	5.39	0.963			1.41	1.51

(*) Superphosphate, and Sulphates of Potash, Soda, and Magnesia.

Quite consistently with the illustrations which have been before adduced, there is, with one exception, a lower, and sometimes a considerably lower, percentage of mineral matter in the dry substance of the more matured "good" than in the less matured "small" tubers. But the point of special interest is, that there is in every case, in each year, a higher, and frequently a much higher, percentage of mineral matter in the dry substance of the diseased, than in that of the sound tubers.

Now, as the mineral matter is fixed, and not subject to loss or gain, it is obvious that its increased amount in relation to that of the dry substance means that there has been a loss of the organic substance of the tuber under the influence of the disease, by which the proportion of the mineral to the organic matter is necessarily increased. It is possible, however, that in some cases the percentage of mineral matter may be slightly too high, owing to the difficulty of thoroughly cleansing the diseased tubers from adherent soil.

The next question is—whether this loss of organic substance is chiefly of the nitrogenous, or of the non-nitrogenous, constituents of the tubers? The columns showing the percentages of nitrogen in the dry substance of the good, the small, and the diseased tubers, in the first season, 1876, afford evidence on this point. There is almost uniformly a lower percentage of nitrogen in the dry substance of the good than in that of the small tubers, and this again is quite consistent with what has gone before. But there is in every case a higher, and sometimes a much higher, percentage of nitrogen in the dry substance of the diseased than in that of the sound tubers. The conclusion is, that it is chiefly, if not exclusively, non-nitrogenous constituents that have been lost; the proportion of the nitrogenous to the non-nitrogenous constituents being thereby increased.

Before leaving Table XI., the average results given in the bottom line for each year may be quoted, in further illustration of the conclusions which have been drawn from a general view of the detailed figures.

Thus, in 1876, the average percentage of dry substance is, in the good tubers 22.52, and in the diseased tubers only 19.35; the average percentage of mineral matter in the dry substance is, in the good tubers 4.16, and in the diseased tubers 5.11. Thus there is, with the disease, a lower percentage of dry matter, and a higher percentage of mineral matter in the dry substance—the two results together showing that there has been a loss of organic substance. Then, again, the percentage of nitrogen in the dry substance is, in the good tubers 1.147, and in the diseased tubers 1.486, or higher in that of the diseased than of the good tubers.

In 1877, with a very different range of percentages with different characters of season, the average percentage of dry matter is, in the good tubers 26.95, and in the diseased tubers only 22.63; whilst in the dry substance itself the average percentage of mineral matter is, in the good tubers 3.88, and in the diseased tubers 4.88.

In 1878, with again a different season, the results are quite

accordant. Thus, the average percentage of dry matter is, in the good tubers 24·2, and in the diseased tubers only 20·02; whilst the average percentage of mineral matter in the dry substance is, in the good tubers 4·06, and in the diseased tubers 5·39.

The evidence is, therefore, consistent and conclusive, that coincidently with the development of the disease, there is a considerable loss of organic substance, and that the loss is chiefly, if not exclusively, of non-nitrogenous matter.

The last columns of the Table show that there is a small but appreciable amount of sugar determinable by the polariscope in the juice of the tubers; but, that there is generally, and on the average, somewhat less in that of the more matured "good" than in that of the small tubers. Further, the difference is the greater in the tubers of 1877, the season of the highest maturation of the three. The indication is, therefore, that the percentage of sugar in the juice diminishes with maturation.

FURTHER EVIDENCE AS TO THE CHANGES INDUCED BY THE DISEASE.

Table XII. (p. 39) gives a comparative view of the composition of the white or only partially diseased, and of the dark or more fully diseased portions of the affected tubers. The first eight columns relate to the composition of the juice, and the last four to that of the marc; that is, the solid residue remaining after the expression of the juice. For the first season, 1876, the results are given for only three plots; but for 1877 and 1878, for each of the ten plots. The analytical results are, however, in some important respects, more complete for the few plots of the first year. It will be convenient to refer first to the more numerous but less complete results for 1877 and 1878.

First as to the composition of the juice of the white, and of the dark, or more completely diseased portion of the tubers. The first two columns do not show uniformly more, or uniformly less, mineral matter in the juice of the dark, than in that of the white portion, but on the average nearly identical amounts. The irregularities are probably partly due to adventitious soil-matter, as before referred to, and this would affect the determinations in the dark, or more diseased portions, more than in those of the white portions.

The third and fourth columns show, however, that there is always very much less nitrogen in the juice of the dark than in that of the white portion—indicating that nitrogen has been appropriated by the fungus in the course of its growth.

The sugar determined by the polariscope is, each year, very much higher in the juice of the white portion of the diseased tubers, than in the juice of sound tubers. Thus, in 1876, there was, in the juice of the sound tubers (see Table XI, p. 36) an average of only 0·50 per cent. of sugar by the polariscope, but in the juice of the white portion of the diseased tubers there was an average of 1·307 per cent. In 1877 there was an average in the juice of the good tubers of only 0·39 per cent., and in

TABLE XII.

EXPERIMENTS ON POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Particulars of the Composition of Diseased Potatoes.

	Per cent. in Fresh Juice.								Per cent. in Dry Marc.				
	Mineral Matter (Ash).		Nitrogen.		Sugar.				Mineral Matter (Ash).		Nitrogen.		
					By Polariscop.		Total reckoned as Glucose.						
	White Portion.	Dark Portion.	White Portion.	Dark Portion.	White Portion.	Dark Portion.	White Portion.	Dark Portion.	White Portion.	Dark Portion.	White Portion.	Dark Portion.	
FIRST SEASON, 1876.													
Ammonium Salts and Mixed Mineral Manure	(2'084)	1'639	0'262	0'191	1'455	0'00			1'60	1'89	0'484	1'718	
Nitrate of Soda and Mixed Mineral Manure		1'114	0'331	0'163	1'067	0'00			0'70	2'08	0'352	1'727	
Farmyard Manure and Superphosphate		1'887	1'542	0'249	0'161	1'400	0'233			0'73	1'72	0'269	1'893
Mean ...		1'886	1'432	0'281	0'172	1'307	0'078			1'01	1'90	0'352	1'613
SECOND SEASON, 1877.													
Unmanured ...	1'152	1'238	0'253	0'126	1'74	0'75			0'586	1'361			
Superphosphate ...	1'644	1'856	0'181	0'139	1'25	0'40			0'832	1'524			
Mixed Mineral Manure (*)	1'648	1'793	0'171	0'103	1'04	0'19	1'786	(0'351)	0'900	2'011			
Ammonium Salts ...	1'065	1'172	0'302	0'170	1'04	0'82			0'868	1'168			
Nitrate of Soda ...		1'166	0'205	0'164		0'62			1'163	1'361			
Ammonium Salts and Mixed Mineral Manure	1'720	1'793	0'279	0'143	0'67	0'52			0'824	1'112			
Nitrate of Soda and Mixed Mineral Manure	1'658	1'612	0'279	0'148	1'05	0'42	1'893	0'539	0'995	1'258			
Farmyard Manure...	1'503	1'578	0'199	0'107	1'32	0'47			0'681	1'443			
Farmyard Manure and Superphosphate	1'520	1'419	0'209	0'098	0'83	0'34			0'673	1'221			
Farmyard Manure, Superphosphate, and Nitrate of Soda	1'485	1'485	0'238	0'153	1'25	0'39			0'912	1'217			
Mean ...		1'488	1'511	0'232	0'135	1'13	0'49	1'839	0'445	0'843	1'370		
THIRD SEASON, 1878.													
Unmanured ...	0'997	0'972	0'205	0'100	3'34	0'84	3'571	1'923					
Superphosphate ...	1'321	1'154	0'164	0'083	2'77	0'67	3'952	1'493					
Mixed Mineral Manure (*)	1'347	1'233	0'143	0'069	2'62	0'55	3'774	1'497					
Ammonium Salts ...	0'821	0'848	0'290	0'146	3'67	0'93	4'566	2'016					
Nitrate of Soda ...	0'698	0'767	0'319	0'134	2'87	0'60	3'788	2'293					
Ammonium Salts and Mixed Mineral Manure	1'188	1'160	0'198	0'074	2'03	0'33	3'125	1'462					
Nitrate of Soda and Mixed Mineral Manure	0'806	1'213	0'211	0'087	2'14	0'85	3'205	2'336					
Farmyard Manure...	1'100	1'066	0'170	lost.	2'48	0'45	3'497	1'377					
Farmyard Manure and Superphosphate	1'132	1'088	0'171	0'078	2'45	0'65	(3'164)	lost.					
Farmyard Manure, Superphosphate, and Nitrate of Soda	1'092	1'088	0'259	0'124	2'57	0'60	3'704	1'497					
Mean ...		1'050	1'059	0'213	0'100	2'69	0'65	3'635	1'766				

(*) Sulphates of Potash, Soda, and Magnesia, and Superphosphate.

that of the white portion of the diseased Potatoes of 1.13 per cent. And, again, in 1878, there was in the juice of the good tubers an average of 1.41 against 2.69 per cent. in the juice of the white portion of the diseased tubers.

The next point to observe is, that the sugar is always very much less in the juice of the dark portion, that is after the growth of the fungus; and, in the few cases in which the total sugar was determined, the reduction in the amounts of it in the juice of the dark portion is very marked; in 1877 from 1.839 to 0.445, and in 1878 from 3.635 to 1.766 per cent.

The evidence clearly points to the conclusion that in the incipient stages of the disease starch is destroyed and sugar formed. This may either serve directly as nutriment to the fungus, in the growth of which carbonic acid is evolved; or the sugar may itself be decomposed, evolving carbonic acid and other products, and hence the loss of non-nitrogenous organic substance.

If we now turn to the composition of the marc of the white and of the dark portions, as shown in the results relating to 1876 and 1877, it is seen that, in every case, there is a very much higher percentage of mineral matter in the dry substance of the dark portion, showing that it had been appropriated by the fungus, of which the dark matter chiefly consists.

As already said, the results show, in every case, very much less nitrogen in the juice of the dark than in that of the white portion, the conclusion being that the fungus had appropriated it in its growth.

Thus, in 1876, the average percentage of nitrogen was, in the juice of the white portion 0.281, and in that of the dark portion 0.172; in 1877, it was in that of the white portion 0.232, and in that of the dark portion only 0.135; and in 1878, the average percentage was in the juice of the white portion 0.213, and in that of the dark portion only 0.10 per cent.

The more complete results, but for the three plots only, in 1876, conclusively show that the nitrogen lost by the juice had been so appropriated in the growth of the fungus. The figures show, in the first place, that there is an average of 1.986 per cent. of mineral matter in the juice of the white, and of only 1.432 per cent. in that of the dark portions, or very much less in the juice of the dark part; that is after the withdrawal for the growth of the fungus. Next as to the nitrogen in the juice:—there is an average of 0.281 per cent. in that of the white or incipiently diseased portion, and of only 0.172 per cent. in that of the dark or more completely diseased—that is, much less after the growth of the fungus. Lastly, as to the juice:—the percentage of sugar as indicated by the polariscope is 1.307 in that of the white, and only 0.078 per cent. in that of the dark part.

That the less amount of both mineral matter and nitrogen in the juice of the dark portion is due to their having been taken up in the growth of the fungus is still more directly and conclusively shown by the results relating to the solid residue, or marc, remaining after the

expression of the juice—the solid residue of the dark part consisting largely of the fungus itself.

Thus, whilst the average percentage of mineral matter in the marc of the white portion is only 1·01, or not very different from that in the dry substance of the sound tuber, the percentage in the marc of the dark portion is 1·90 or nearly double; and, again, whilst the percentage of nitrogen in the dry solid matter of the white portion is only 0·352, in that of the dark portion it is 1·613, or several times more. It is thus clearly shown, therefore, that the nitrogen lost by the juice has been appropriated in the growth of the fungus.

To sum up the evidence as to the changes suffered by the tuber under the influence of the disease, it would seem that the first material change is the destruction of starch, and the formation of sugar, apparently partly cane sugar and partly glucose. There is a considerable loss of organic, and chiefly non-nitrogenous, substance. This may be due in part to the decomposition of the produced sugar, and the evolution of carbonic acid and other products. But, it is, perhaps, mainly due to the evolution of carbonic acid, as a coincident of the growth of the fungus deriving its nutriment from ready-formed organic substance; this being a characteristic action in the growth of these non-chlorophyllous plants.

Finally, as the disease progresses, a very large proportion of both the mineral matter and the nitrogenous substance of the tuber is accumulated in the fungus. This is more especially the case in regard to the nitrogen, and in this fact we have doubtless some explanation of the further fact to which I have prominently called attention—namely, that the disease develops much more in tubers grown by highly nitrogenous manures, and having a highly nitrogenous juice, than in those grown under contrary conditions.

I have thus directed attention to the facts which the investigation has brought to light, as to the conditions, both of season and manuring, under which the disease is more or less developed, and also those as to the changes which take place in the composition of the tubers under the influence of the disease. It will, perhaps, be thought that I have stopped short of the point of most practical interest—namely, the suggestion of means of prevention of the disease. I do not propose to offer any specific recommendations on this point. At the same time, I think it will be granted, that any contribution to a clearer understanding of the conditions, and of the result, must lead to a better understanding of the cause, and that this, in its turn, is at any rate an essential step towards means of mitigation or prevention.

SUMMARY.

I have now discussed, in considerable detail, the conditions, both of season and manuring, upon which the successful growth of the Potato depends, and the results may be very briefly summarised as follows. Although of course requiring a full available supply of

the mineral constituents within the soil, it has been seen that, these conditions being provided, the amount of produce is largely dependent on the available supply of nitrogen within the soil. In practice farm-yard manure is mainly relied upon. It is used in very large quantities per acre, and is sometimes supplemented by liberal dressings of artificial manures, both mineral and nitrogenous. The crop removes, however, a less proportion of the nitrogen of farm-yard manure than any other farm crop. It was seen that the most characteristic result of the increased growth under the influence of nitrogenous manures, was an increased production of the non-nitrogenous constituent—*starch*. It was shown, however, that for 1 of nitrogen supplied in manure, the increased amount of starch obtained in the Potato was less than the increased amount of sugar obtained in the Mangel Wurzel, and much less than that yielded in sugar-beet. It was further shown that although a larger proportion of the total nitrogen of the Potato is in the albuminoid condition than in the case of root-crops, yet from four-fifths to five-sixths, or even more, of the total nitrogen, and from two-thirds to three-fourths, or more, of the total albuminoids, of the tuber, may exist in the soluble condition in the juice; and it is obvious that in the usual mode of cooking the Potato for the table, most of this is lost as food.

Next it was shown that the disease, though largely dependent on season, developed much more in tubers grown by highly nitrogenous manures, and containing a juice rich in nitrogen, than under contrary conditions. Finally, it has been shown that a result of the disease is a destruction of starch, the formation of sugar, the loss of organic substance, and the growth of the fungus at the expense of the substance of the tuber.

YIELD OF POTATOES IN DIFFERENT COUNTRIES.

I propose, in conclusion, to call attention to such information as is available, as to the area devoted to the Potato, and the amount of the crop obtained, in the different divisions of the United Kingdom, and in a number of Foreign Countries.

Table XIII. (p. 43) gives the estimates, according to the "Agricultural Returns," of the area under the crop, the aggregate produce, and the average produce per acre, in 1884, 1885, 1886, and 1887, and the mean for the four years, for England and Wales, for Scotland, and for Ireland; also for Great Britain as a whole, and for the United Kingdom as a whole.

The figures show, that the area under the crop averaged over the four years, in England and Wales nearly 404,000 acres, and in Scotland about 153,000 acres, or not much less than two-fifths the area of England and Wales together. Over the same period, the average aggregate produce per annum was, in England and Wales rather over

2½ million tons, and in Scotland about 900,000 tons; or rather more than one-third as much as England and Wales, and over one-fourth of the total of Great Britain. It is further seen that, in Great Britain as a whole, the average area under the crop is about 557,000 acres, and the average aggregate produce rather more than 3,400,000 tons.

TABLE XIII.
POTATOES.

Area under the crop, aggregate produce, and produce per acre, in the United Kingdom.
Four seasons, 1884 to 1887 inclusive.

	1884.	1885.	1886.	1887.	Average.
AREA UNDER THE CROP.					
	Acres.	Acres.	Acres.	Acres.	Acres.
England	401,201	359,026	363,782	369,243	403,758
Wales	40,711	40,711	40,499	40,570	40,370
Scotland	163,847	148,994	149,680	149,889	153,060
Great Britain ...	565,048	548,731	553,961	559,692	556,648
Ireland	798,952	797,292	799,847	796,839	798,258
United Kingdom ...	1,364,000	1,346,023	1,353,808	1,356,531	1,355,106
ESTIMATED AGGREGATE PRODUCE.					
	Tons.	Tons.	Tons.	Tons.	Tons.
England	2,756,395	2,182,712	2,111,862	2,300,338	2,515,159
Wales	966,908	212,289	214,791	282,288	261,594
Scotland	966,908	803,523	841,110	982,288	903,432
Great Britain ...	3,743,203	3,198,504	3,167,763	3,564,894	3,418,591
Ireland	3,040,352	3,175,738	2,667,724	3,569,402	3,113,304
United Kingdom ...	6,783,555	6,374,242	5,835,487	7,134,296	6,531,895
ESTIMATED AVERAGE YIELD PER ACRE.					
	Tons.	Tons.	Tons.	Tons.	Tons.
England	6·87	6·08	5·81	6·23	6·23
Wales	6·02	5·21	5·30	6·06	5·65
Scotland	6·02	5·39	5·62	6·56	5·90
Great Britain ...	6·62	5·83	5·72	6·37	6·14
Ireland	3·81	3·98	3·34	4·48	3·90
United Kingdom ...	4·97	4·74	4·81	5·26	4·82

Ireland is seen to have an average area of nearly 800,000 acres under the crop, or not far from one-and-a-half time as much as Great Britain; whilst its aggregate produce is notably less than that of Great Britain.

The aggregate area under Potatoes in the United Kingdom is rather over 1½ million acres, and the aggregate produce is rather more than 6½ million tons of tubers.

Turning now to the average produce per acre, the lower division of the table shows, that England and Wales together are estimated to yield about 6½ tons; Wales apparently yielding rather less than England. The average yield of Scotland is rather less than 6 tons per

acre. These together give about $6\frac{1}{2}$ tons as the average yield of tubers per acre per annum in Great Britain.

For Ireland the estimates show an average yield per acre of less than 4 tons, against more than 6 tons in Great Britain. It may be mentioned that the yield per acre given for Ireland, where the Potato is still of great importance as a supply of food for the people, is less than twice as much as was obtained at Rothamsted, over twelve years in succession on the same land, without any manure; it is scarcely more than was obtained by mineral manure alone; and considerably less than two-thirds as much as was yielded by mineral and nitrogenous manures together. It is clear, therefore, that the condition of the land, the cultivation, and the treatment of the crop, are, in Ireland, much inferior to those in the rest of the United Kingdom.

Table XIV. (below) gives similar particulars for 13 foreign countries, arranged in the order of their highest average produce per acre. Wherever the records were available, the averages for five recent years are given; and in other cases the best data at command have been taken. In all cases, however, the Table shows for what years the averages are calculated.

TABLE XIV.
POTATOES.

Area under the Crop, Aggregate Produce, and Produce per acre, in different countries.

	Number of years.	Seasons.	Average area under the Crop.	Estimated Aggregate produce.	Average yield per acre.
			Acres.	Tons.	Tons.
Norway	3	1885, '70, '75	80,417	482,233 (+)	6.01
Belgium	6	1878-'83	492,412 (*)	2,794,497 (±)	4.54
Holland	5	1880-'84	350,284	1,434,358 (+)	4.09
Italy	6	1875-'80	189,210	693,042	4.09
Australasia	5	1880-'84	97,577	370,649	3.81
Germany	5	1882-'86	7,119,291	23,633,011	3.31
Sweden	5	1881-'85	381,616	1,224,646 (+)	3.21
Russia in Europe	5	1883-'87	3,172,935 (†)	6,713,187 (+)	2.93 (||)
France	5	1880-'84	3,321,830	9,289,499 (+)	2.80
Austria	5	1881-'85	2,570,082	7,102,672 (+)	2.76
Hungary	5	1882-'86	1,006,147	2,618,321 (+)	2.62
Denmark	7	1881-'87	110,306 (†)	316,547	2.59 (†)
United States	5	1881-'85	2,197,877	4,139,313 (+)	1.87

(*) 1880 only. (+) Recorded in bushels, reduced to tons, reckoning 56 lbs. per bushel.

(±) Average of seven years, 1880-'86. (†) 1881 only. (||) 1872 only.

A glance at the Table shows that, as a rule, it is the countries of small area under the crop, and generally those of small total area, that stand at the head of the list, and show the highest yield per acre. Of these, Norway stands first, with an average of about 6 tons per acre, or rather less than Great Britain. Belgium comes next with an average of little more than $4\frac{1}{2}$ tons, or about three-fourths as much as Great Britain. Then come Holland and Italy, with little over 4 tons per acre, or scarcely two-thirds as much as Great Britain.

Turning now to some of the larger countries, with larger areas under the crop, it is seen that Germany, where the Potato is much

grown as an industrial crop, has an area devoted to it about thirteen times as large as in Great Britain, and yields about seven times the aggregate crop. But its average yield per acre is only 3.31 tons, or little more than half as much as that of Great Britain.

Then there is France, which, compared with Great Britain, has about six times the area under the crop, but yields less than three times as much aggregate produce, and gives considerably less than 3 tons per acre; that is, less than half as much per acre, as Great Britain, and even considerably less than Ireland.

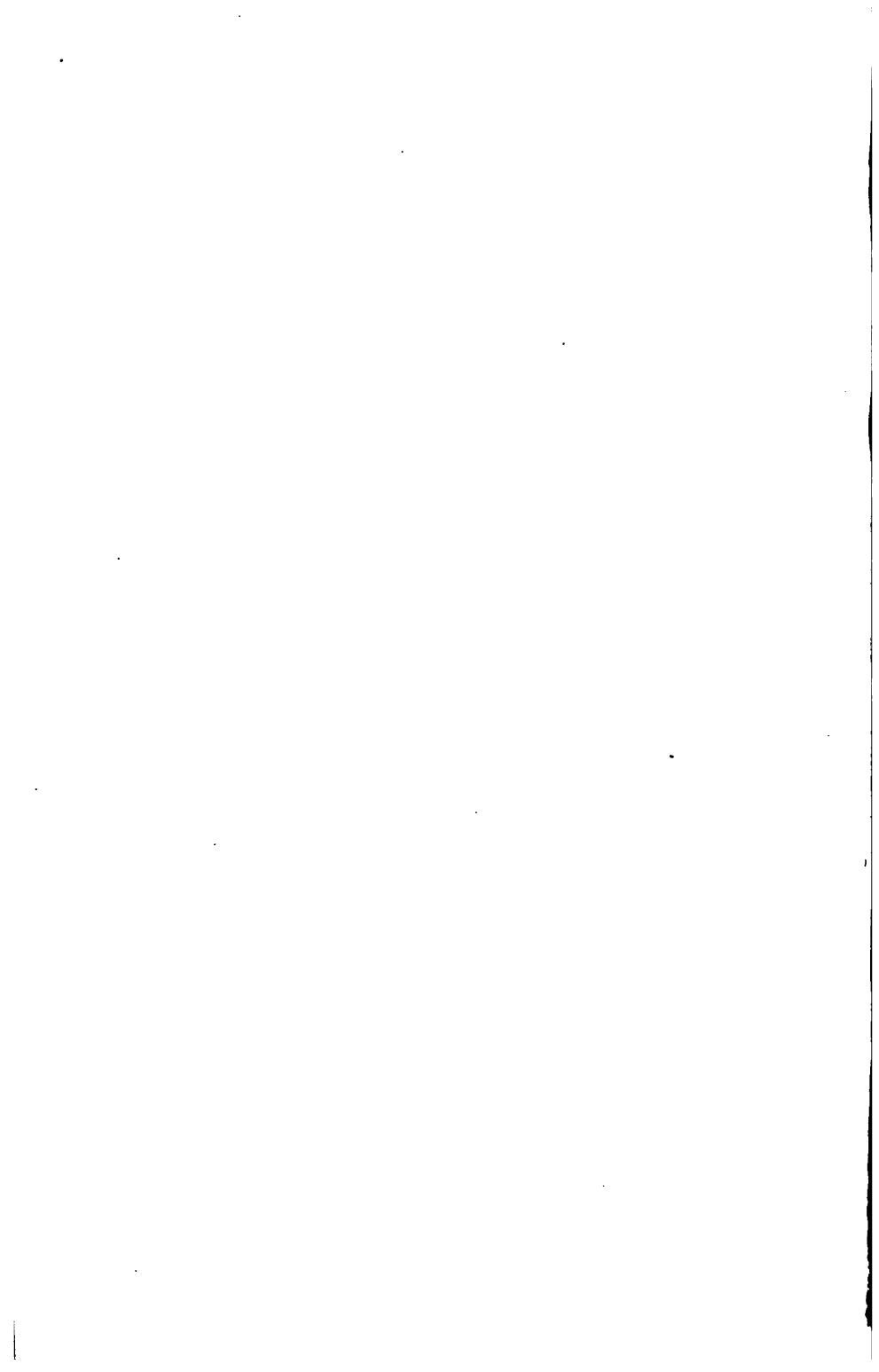
Russia in Europe, again, according to the data, which are, however, incomplete and discordant, has, compared with Great Britain, nearly six times the aggregate area under the crop, but yields scarcely twice the aggregate produce; and, like France, yields less than 3 tons per acre; that is less than half as much as Great Britain.

Lastly, the United States, with nearly four times the area under the crop, but only about $1\frac{1}{2}$ time as much aggregate produce as Great Britain, yields an average of less than 2 tons per acre, or less than one-third as much as Great Britain.

Here, then, of 13 countries where the Potato is largely grown, their aggregate area under the crop being about 21 million acres, and their aggregate produce about 61 million tons, there is not one that reaches the average produce, per acre, of Great Britain. Norway, Belgium, and Holland, the most nearly approach our yield; and it is of interest to observe that these, and Denmark, are the countries that most nearly approach the United Kingdom in yield per acre of wheat and barley also.

It is, then, only the countries of small total area, and of small area under the crop, that at all nearly equal us in yield per acre; and among them, Belgium and Holland, the second and third on the entire list, more nearly approach us than any other, in *density of population*, and in the *amount of live-stock kept per acre*, and consequently in the supply of *manure*. Both these countries, too, have good home markets, besides their exports of agricultural produce.

It will be said, perhaps, that the better yield of potatoes per acre in Belgium than in most of the other countries, is due to the prevalence of peasant proprietors and small holdings; but, if this be so, how is it that it still yields only about three-fourths as much as Great Britain? Then, again, Germany yields per acre, little more than half as much potatoes, and only about two-thirds as much of either wheat or barley—and France less than half as much potatoes, and less than three-fifths as much wheat or barley—as Great Britain.



RESULTS OF EXPERIMENTS AT ROTHAMSTED,
ON THE
GROWTH OF
LEGUMINOUS CROPS,

FOR MANY YEARS IN SUCCESSION
ON THE SAME LAND;

BEING

(WITH ADDITIONS)

A LECTURE DELIVERED NOVEMBER 1, 1889,

AT THE

ROYAL AGRICULTURAL COLLEGE,
CIRENCESTER,

BY

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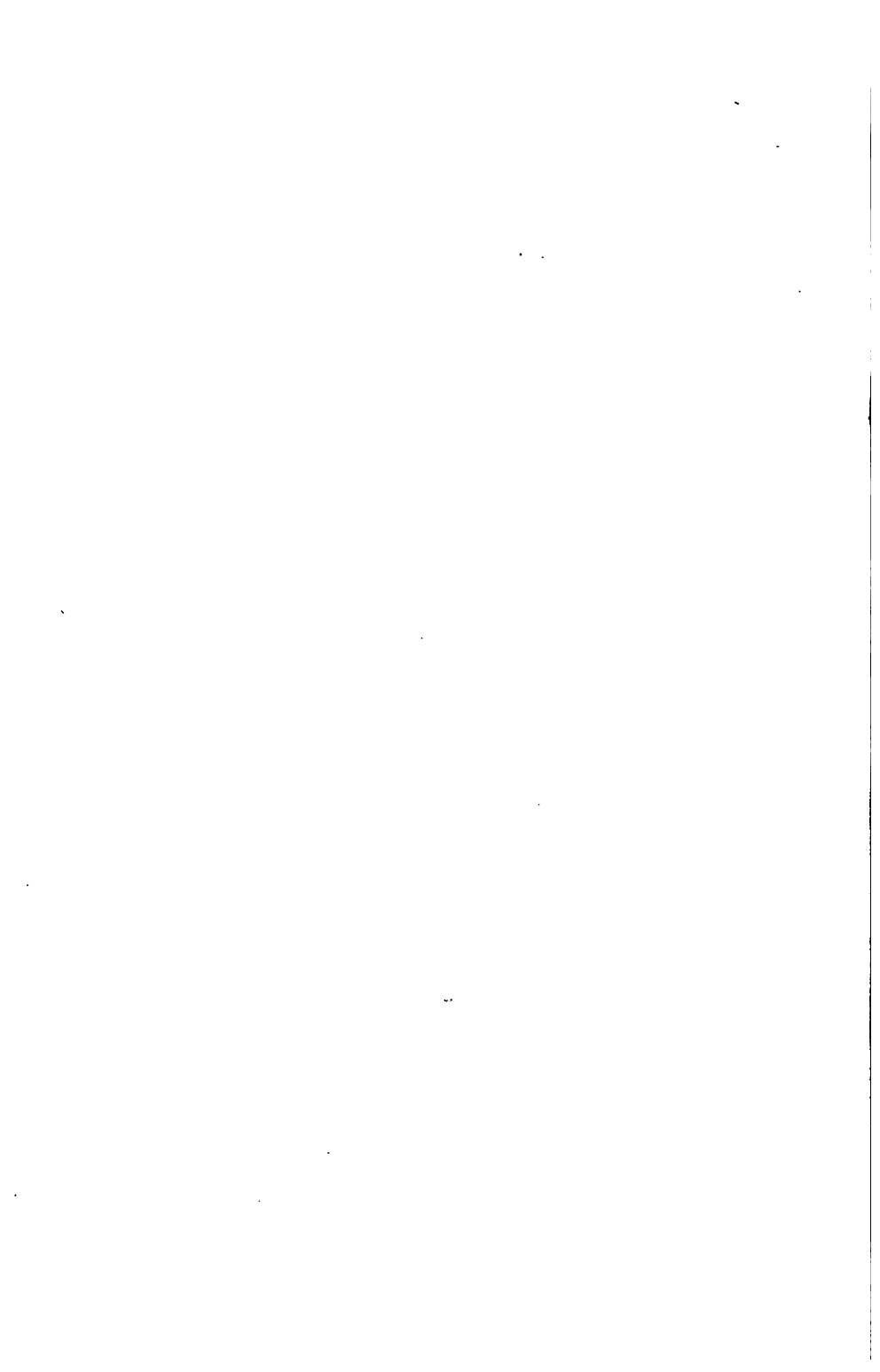
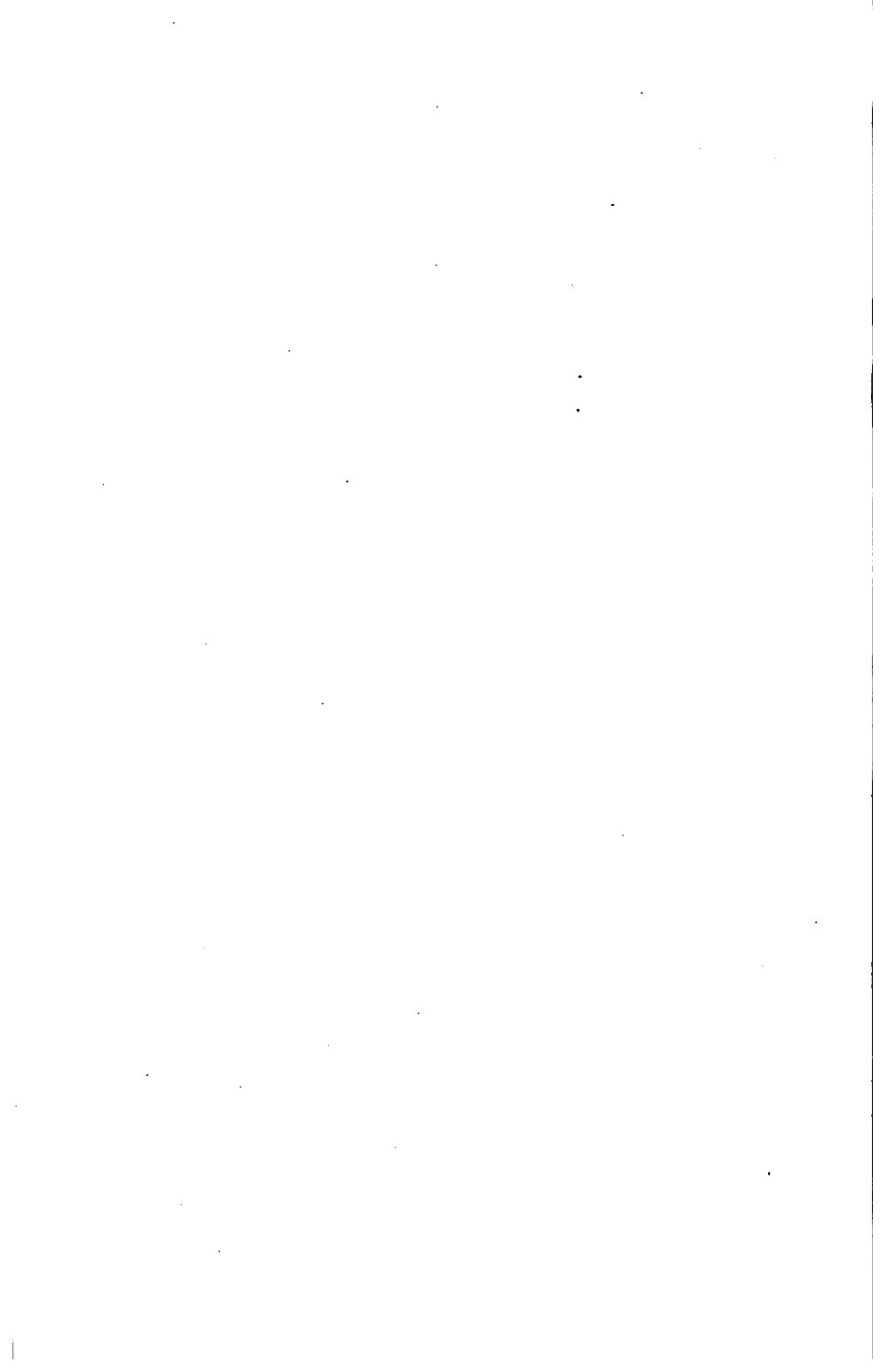


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RESULTS OF EXPERIMENTS AT ROTHAMSTED, ON
THE GROWTH OF LEGUMINOUS CROPS,
FOR MANY YEARS IN SUCCESSION ON THE SAME LAND.

INTRODUCTION.

The subject of my lecture to-day is—the conditions, and the results of growth, of Leguminous Crops ; and, as on former occasions, I propose to draw my illustrations largely from the results of field experiments, and other investigations, conducted at Rothamsted.

In former lectures I have, in a similar way, considered the conditions and the results of growth—of Wheat, and of Barley, as representatives of the great gramineous family ; of some varieties of Turnips, representing the *Cruciferae* ; of some varieties of Beet, representing the *Chenopodiaceae* ; and of Potatoes, of the *Solaneae*.

It was found that, within certain limits, the requirements, and the results of growth, of different members of one and the same family, showed certain characteristics in common ; whilst those of different families showed more or less of distinctive character. Nevertheless, there are some important points of similarity, as well as of contrast, between the requirements of the agricultural representatives of the *Gramineae*, the *Cruciferae*, the *Chenopodiaceae*, and the *Solaneae*.

It will be seen, however, that the agricultural representatives of the *Leguminosae*, all of which are included in the sub-order *Papilionaceae*, and some of which are of much importance in our agriculture, show very marked differences, as compared with those of any of the other families I have enumerated.

It so happens that, both the scientific interest, and the practical value, of these crops, whether as elements in rotation, or as grown in the mixed herbage of grass-land, depend very largely on the amount of nitrogen which they contain, and on the sources of their nitrogen ; and especially on the great differences in these respects, between them, and the representatives of the other families with which they are grown, either in alternation in our rotations, or in association in our meadows and pastures.

So much is this the case, that it is essential to a proper understanding and appreciation, of the characteristics of growth of these crops, and for the illustration of their value and importance as depending on those characteristics, to compare and to contrast the conditions and results of their growth, with those of the crops of other families.

I will first call attention to the difference in the amounts of nitrogen assimilated over a given area by different crops, when each is grown

for many years in succession on the same land, without any nitrogenous manure; or when grown in alternation one with another, also without nitrogenous manure; that is to say, under conditions in which the soil is to a great extent exhausted of accumulations of nitrogen due to recent supplies by manure, and when, therefore, the plants have to rely largely on what may be called the natural resources of the soil, and on those of the atmosphere.

I shall next show the effects of artificial supplies of nitrogen, on the growth of the different descriptions of plant, on the amount of nitrogen they assimilate, and on the amount and character of their products.

Lastly, I shall adduce evidence of quite other kinds, as to the sources of the nitrogen, more especially of the *Leguminosæ*; a question which has been the subject of experimental enquiry, and at times of active controversy, for about half a century; which has in recent years assumed a somewhat new aspect; but which cannot even yet be said to be conclusively settled.

YIELD OF NITROGEN PER ACRE PER ANNUM IN DIFFERENT CROPS, WITHOUT NITROGENOUS MANURE.

Table I. (p. 3), shows the yield of nitrogen per acre per annum, with mineral, but without any nitrogenous manure—in Wheat and in Barley as *Gramineous* crops, in Turnips as representatives of the *Crucifera*, in Sugar-Beet and Mangel-Wurzel of the *Chenopodiaceæ*, and in Beans and Clover as *Leguminous* crops, when each is grown for many years in succession on the same land. It also shows, the amounts of nitrogen yielded per acre, when Turnips, Barley, a Leguminous crop, and Wheat, are grown in an actual course of rotation, also with mineral, but without nitrogenous manure.

Incidentally it is to be noticed that, in the case of each of the crops—Wheat, Barley, and Beans—thus grown year after year on the same land for many years in succession without nitrogenous manure, there was a reduction in the yield of nitrogen per acre per annum, over the second period compared with the first; that is, as the accumulations within the soil became reduced.

Disregarding this tendency to reduced yield, it is seen that, over the same period of 24 years, with full mineral but without nitrogenous manure, the wheat yielded an average of 22.1 lbs., and the barley 22.4 lbs. of nitrogen per acre per annum; the two allied crops, therefore, yielding almost identical amounts, in their above-ground produce, without nitrogenous manure, on soil very poor in available nitrogen, so far as accumulations due to recent applications of nitrogenous manure are concerned.

Turning now to the yield of nitrogen in the root-crops,—Turnips, Sugar-Beet, and Mangel-Wurzel—it may be mentioned that, prior to the period referred to in the Table, Turnips had been grown for a number of years, and had yielded 42 lbs. of nitrogen per acre per

annum, due to the accumulations from comparatively recent nitrogenous manuring. But, it is seen that, after these accumulations had been reduced, Swedish Turnips gave over 15 years, an average of only 18·5 lbs., Sugar-Beet over the next 5 years, an average of only 14·7 lbs., and Mangel-Wurzel over the succeeding 10 years, an average of only 14·0 lbs. of nitrogen, per acre per annum. Or, reckoned over the whole period of 30 years, after the recent accumulations had been worked out, the root-crops gave an average of only 16·4 lbs. of nitrogen per acre per annum.

TABLE I.

Nitrogen per acre per annum, in various Crops grown at Rothamsted, with Mineral, but without Nitrogenous Manure.

						Duration of Experiment.	Average Nitrogen per acre per annum.	
							lbs.	
Wheat	..	..	..	..	..	12 years, 1852-1863	27·0	
						12 years, 1864-1875	17·2	
						24 years, 1852-1875	22·1	
Barley	..	..	..	..	..	12 years, 1852-1863	26·0	
						12 years, 1864-1875	18·8	
						24 years, 1852-1875	22·4	
Root-crops	{	Swedish Turnips		..	..	*15 years, 1856-1870	18·5	
		Sugar Beet		..	..	5 years, 1871-1875	14·7	
		Mangels		..	..	10 years, 1876-1885	14·0	
		Total		..	..	30 years, 1856-1885	16·4	
Beans	..	..	..	..	..	12 years, 1847-1858	61·5	
						†12 years, 1859-1870	29·5	
						24 years, 1847-1870	45·5	
Clover	..	..	..	..	..	‡22 years, 1849-1870	39·8	
Rotation (8 courses)	{	1. Swedish Turnips		..	..	32 years, 1852-1883	33·3	
		2. Barley		..	..		23·5	
		3. {	Clover (2 courses)		..		..	124·5
			Beans (6 courses) ..		..		..	40·5
		Average Clover and Beans					61·5	
		4. Wheat		..	..		35·9	
Average all Crops ..		..	..	38·6				

* 13 years crop, 2 years failed.

† 9 years beans, 1 year wheat, 2 years fallow.

‡ 6 years clover, 1 year wheat, 3 years barley, 12 years fallow.

§ Superphosphate only.

It is remarkable, how very similar is the amount of nitrogen annually accumulated in Gramineous, Cruciferous, and Chenopodiaceous crops, after the soil had been exhausted of the more recent and more

readily available nitrogenous accumulations. Thus, over the second half of the period, the Wheat gave 17.2, and the Barley 18.8 lbs., against 16.4 lbs. over 30 years in the various root-crops.

We now come to the yield of nitrogen in Leguminous crops, grown under somewhat similar circumstances as to the soil supplies of it. Referring first to the results obtained with Beans, it is seen that, over the first half of the period of 24 years, the average annual yield of nitrogen in the crop was 61.5 lbs. per acre; whilst, over the second 12 years, in 3 of which, however, the crop failed, so that there were only 9 years of Beans, 1 year of Wheat, and 2 years of Fallow, the annual yield was less than half as much, or only 29.5 lbs. per acre. Nevertheless, the average yield over the 24 years without any nitrogenous manure, was 45.5 lbs. per acre per annum. That is to say, under very similar conditions as to soil supply, the highly nitrogenous Leguminous crop, Beans, has yielded over a given area, twice as much nitrogen as either Wheat or Barley, and more than twice as much as the root-crop.

The next results relate to the Leguminous crop, Clover. It is well known that Clover fails when it is attempted to grow it too frequently on the same land; and in the case recorded in the Table, it happened that Clover was obtained in only 6 years out of the 22 for which the yield of nitrogen is given; so that there are included, owing to the failures, 1 year of Wheat, 3 years of Barley, and 12 of Fallow. Notwithstanding this, there was, with the occasional interpolation of the Clover, an average yield, over the 22 years, of 39.8 lbs. of nitrogen per acre with mineral, but without nitrogenous supply.

The last results in the Table relate to the yield of nitrogen per acre per annum, over 32 years of an actual rotation of crops; that is, over 8 courses of 4 years, each course comprising Swedish Turnips, Barley, Clover (or Beans), and Wheat, which, as in the other cases, were grown with a purely mineral manure (in this case superphosphate of lime alone), but without any nitrogenous supply.

The figures show that, when the various crops are thus grown in alternation one with another, instead of each separately year after year, on the same land, the yield of nitrogen is generally greater, and sometimes much greater. Thus, whilst the mineral manured Swedish Turnips, yielded only 18.5 lbs. of nitrogen per acre per annum, when grown year after year on the same land, they yielded 33.3 lbs. when grown in rotation; the Barley yielded 22.4 lbs. when grown continuously, and 23.5 lbs. in rotation; the Beans 45.5 lbs. grown year after year, and only 40.5 lbs. in rotation, but this is very much more than the yield of the continuous Beans in the second half of the period, which was only 29.5 lbs.; the Clover yields an average of 124.5 lbs. in rotation, against only 39.8 lbs. when it was attempted to grow it continuously, and it frequently failed; and the Wheat succeeding the Leguminous crop in rotation, yields 35.9 lbs. against only 22.1 lbs. grown continuously. Lastly, the rotation crops taken together (including *Leguminosæ*), have yielded, over 32 years, an average of 38.6 lbs. of nitrogen per acre per annum, against only about half as much in either

Wheat, Barley, or Roots, grown under the same manurial conditions, that is without nitrogenous supply, but each grown continuously on the same land; whilst, in an exactly corresponding rotation, but with fallow instead of a leguminous crop in the third year, the average annual yield of nitrogen over the 32 years, was only 24·3 lbs.

It is seen, then, that the increased yield of nitrogen in the rotation-crops, was largely due to the interpolation of the *Leguminosæ*, the Clover or the Beans; in part owing directly to the large yields of nitrogen in these crops themselves, but in part to the increased yields in the Wheat immediately succeeding the Leguminous crop, which, especially the Clover, would leave an effective nitrogenous crop-residue, but, in part also, to some effect from this increased crop-residue on the other crops of the course; and lastly, to the fact, that the various crops grown in alternation have different root ranges, and grow during different periods of the season. The Wheat, in fact, yielded nearly as much after the removal of the highly nitrogenous Leguminous crop, as on a corresponding plot left Fallow; from which, therefore, no nitrogen had been removed in the produce in the preceding year.

The next illustrations show more strikingly still, the greater yield of nitrogen in Leguminous than in Gramineous crops, grown under equal soil conditions. They relate to the yield of nitrogen in Barley and in Clover, grown side by side in the same field; and the results are given in Table II.

TABLE II.
Nitrogen per acre per annum, in Barley and Clover, grown in Little Hoosfield, Rothamsted.

										Nitrogen per acre.
										lbs.
1873	Barley	..	..	..	..	..	..	..	..	37·3
	Clover	..	..	..	..	..	..	..	..	151·3
1874	Barley	{	After Barley	..	..	..	..	..	..	39·1
		{	After Clover	..	..	..	..	..	..	69·4
	Barley after Clover more than after Barley									30·3

The field had grown one crop of Wheat, one crop of Oats, and three crops of Barley in succession with artificial mineral and nitrogenous manures, but without any farm-yard or other organic manure. In 1872, Barley was again sown; on one half alone, and on the other half with Clover. In 1873, Barley was again grown on the one half, but the Clover on the other. The Table shows that the Barley yielded 37·3 lbs. of nitrogen per acre, whilst the three cuttings of Clover contained 151·3 lbs. In the next year, 1874, Barley was grown over both portions: and on the one where Barley had yielded 37·3 lbs. of nitrogen in the previous year, it now yielded 39·1 lbs.; but on the portion where the Clover had yielded 151·3 lbs., the Barley succeeding it yielded 69·4 lbs. That is to say, the Barley yielded 30·3 lbs. more

nitrogen after the removal of 151·3 lbs. in Clover, than after the removal of only 37·3 lbs. in Barley.

The fact is, that the Clover had not only yielded so much more nitrogen in the removed crops, but it had also left the surface soil considerably richer in nitrogen. Thus, in October, 1873, after the removal of the Barley and the Clover, samples of soil were taken from 10 places on each of the two portions, and the nitrogen was determined in the samples from each of 4 of the individual holes separately, in the mixture of the 4, and in the mixture of the samples from the other 6 places. The determinations in the numerous separate samples consistently showed that, to the depth of 9 inches, the Clover-land soil which had yielded so much more nitrogen in the crops, was nevertheless determinably richer in nitrogen than the Barley-land soil, which had yielded so much less. This is sufficiently illustrated by the following figures, showing the mean percentage of nitrogen in the dry fine soil, of the Clover, and of the Barley-land, respectively :—

					Mean per cent. Nitrogen.
In Clover-land soil	...	...	...	...	0·1566
In Barley-land soil	...	...	...	...	0·1416

This was the case notwithstanding that all visible vegetable debris had first been removed from the samples. It was further found, that the above- and under-ground vegetable residue picked from the Clover-land samples, was much more in quantity, and contained much more nitrogen, than that from the Barley-land samples.

In 1874, and in 1875, barley only was sown over both portions. In 1876, barley was again sown over the whole of the land, with Clover as well on the portions where it had been grown in 1873 ; but the plant failed in the winter, and gave no crop in 1877. In 1877, Barley was again sown over the whole ; this time with Clover on half of the previously Clover portion, and on half of the previously only Barley portion. In the autumn of 1877, soil samples were again taken ; this time from 4 places on each of the differently cropped portions. The determinations of nitrogen in the surface soils consistently showed, as before, a higher percentage where Clover had grown than where only Barley had grown.

It is, of course, well known in agriculture, that the growth of Clover, which removes much more nitrogen than a cereal crop, increases the produce of a succeeding cereal as if nitrogenous manure had been applied. But what I wish specially to direct attention to is, the fact that a Leguminous crop accumulates a great deal more nitrogen over a given area than a Gramineous one under equal soil conditions.

YIELD OF NITROGEN IN THE CROPS OF A MANURED ROTATION.

Before considering the effects of direct nitrogenous manures on the different crops, it will be well to form some idea of the amount of nitrogen yielded in fairly good crops grown in rotation, with fairly liberal manuring. This point may conveniently be illustrated by the

results given in Table III. (below), which show the amounts of nitrogen in the crops grown in the experimental rotation at Rothamsted, for which a full manure, both mineral and nitrogenous, is applied for the Turnips commencing each course. The whole of the crops, roots and leaves in the case of the Turnips, and both corn and straw in that of the Cereals and the Beans, are removed from the land, and the figures show the average amounts of nitrogen in the crops over 8 courses in each case, that is over a period of 32 years in all.

TABLE III.

Yield of Nitrogen in Crops grown in four-course rotation, with artificial mineral and nitrogenous manures.
8 courses, 32 years, 1852-1883.

											Average yield of Nitrogen per acre per annum.
1.	Swedish Turnips..	..	..	..	..	..	..	..	..	..	lbs. 80·6
2.	Barley ..	..	..	..	..	..	..	..	..	..	40·7
3.	{ Clover (2 courses)	..	..	..	..	..	..	..	..	..	167·0
	{ Beans (6 courses)	..	..	..	..	..	..	..	..	..	63·6
	Average Clover and Beans ..	..	..	..	..	..	..	..	..	..	89·5
4.	Wheat ..	..	..	..	..	..	..	..	..	..	43·7
	Average of all crops ..	..	..	..	..	..	..	..	..	..	63·6

If we compare the amounts of nitrogen in these crops, for which nitrogenous as well as mineral manures were applied, with those obtained in a corresponding rotation but without nitrogenous manure, as shown in Table I. (p. 3), it is seen that every one of the crops, the Roots for which the manure was directly applied, the Cereals, and the Leguminous crops, all yield much more nitrogen than when no nitrogenous manure was applied. The amounts of nitrogen obtained in the Cereals are about the same as, or perhaps rather less than, in average good crops grown in ordinary farm practice. The amounts obtained in the Turnips are also perhaps rather less than in average good crops, and considerably less than in a good crop of Mangel-Wurzel. The amounts in the Beans are also less than in a good crop of Beans, grown on suitable Bean-land, but the amounts in the Clover are more than in the average of crops grown in ordinary rotation.

Taking the results as they stand, it is seen that, both the Roots and the Leguminous crops accumulate much more nitrogen than either of the Cereals grown in alternation with them. Lastly, whilst the average yield of nitrogen, per acre per annum, over 32 years was, without nitrogenous manure only 38·6 lbs. (see Table I.), it is, with nitrogenous manure, 63·6 lbs.; and compared with this latter amount, it may be mentioned that, in a similarly manured rotation, but with fallow instead of a leguminous crop in the third year, the annual yield of nitrogen was only 39·9 lbs.

PERCENTAGE OF NITROGEN, IN THE DRY SUBSTANCE OF
VARIOUS CROPS.

Not only is the yield of nitrogen per acre much less in the Cereal crops, but the percentage of nitrogen in the dry substance of the Gramineous produce is much less than in that of the Leguminous produce. This is illustrated in Table IV. (below), which shows the average percentage of nitrogen in the dry substance of various crops.

TABLE IV.
Average Percentage Nitrogen in the dry substance of various Crops.

	Corn or Roots.	Straw or Leaf.
	Per cent.	Per cent.
Wheat	2.12	0.54
Barley	1.96	0.47
Oats	2.33	0.60
Maize	1.93	
Peas	4.24	1.21
Beans	4.71	1.09
White Turnips	2.25	3.7
Yellow Turnips	2.22	
Swedish Turnips	2.27	4.0
Mangel Wurzel	1.76	2.9
Potatoes	1.00	
HAY.		
Meadow Hay	1.79	
Clover Hay	2.89	

Thus it is seen, that the corn of the Leguminous crops, Beans and Peas, contains more than twice as high a percentage of nitrogen in its dry substance as that of the Gramineous grains. The dry substance of the Leguminous straws, also contains about twice as high a percentage of nitrogen as that of the Cereal straws. Again, the dry substance of Clover-hay contains not far short of twice as much nitrogen as that of Meadow-hay. Lastly, the dry substance of the Roots contains about the same percentage of nitrogen as that of the Cereal grains, but only about half as much as that of the Leguminous corn. The leaves of the Root-crops are, however, high in nitrogen.

The general result is, then, that the *non*-Leguminous crops, especially those of the Gramineous family, are characterised, both by yielding much less nitrogen in their produce over a given area, and by containing a much lower percentage of nitrogen in their dry substance, than the Leguminous crops. Bearing these facts in mind, let us now turn to the consideration of the effects of direct nitrogenous manures on the various crops.

EFFECTS OF NITROGENOUS MANURES IN INCREASING THE
PRODUCE OF VARIOUS CROPS.

I need not remind you that, under the conditions in which the crops are grown in ordinary agriculture, nitrogenous manures have very marked effects in increasing the amounts of produce of Wheat, of Barley, of Turnips, of Mangels, and of Potatoes ;—that is, of the comparatively low-in-nitrogen *non*-Leguminous crops. For detailed evidence on the point, I may refer you to my former lectures relating to these various crops. But I may recall to mind the fact that—in the case of Wheat and Barley the increased produce consists characteristically of the non-nitrogenous substances starch and cellulose, in that of the Root-crops of the non-nitrogenous substance sugar, and in that of Potatoes of the non-nitrogenous substance starch.

Table V. (p. 10), illustrates very strikingly the influence of nitrogenous manures in increasing the production of the non-nitrogenous constituents of our crops.

The first column of figures shows, the estimated amounts of carbon, per acre per annum, in the total produce of Wheat and of Barley, in the roots of Sugar-Beet and Mangel-Wurzel, in the tubers of Potatoes, and in the total produce of Beans ; in each case when grown by a complex mineral manure without nitrogen, and also with the same mineral manures with nitrogenous manure in addition. The second column shows the estimated gain of carbon ; that is, the increased amount of it assimilated under the influence of the nitrogenous manures. The third column shows the estimated increased production of total carbohydrates, under the influence of the nitrogenous manures ; and the last column the estimated gain of carbohydrates for 1 of nitrogen in manure.

The mode of calculating the amounts of carbon and of carbohydrates is as follows. From the amount of dry substance in the crops, the amounts of mineral matter and of nitrogenous substance are deducted ; and the remainder represents the amount of carbohydrates. The amount of carbon in the nitrogenous substance is calculated ; and then that in the carbohydrate, on the assumption that, in the Wheat, Barley, and Beans, starch and cellulose are the main products ; in the Sugar-Beet and Mangel-Wurzel, cane-sugar, pectine, and cellulose ; and in the Potatoes, starch and cellulose. Such estimates can, obviously, only be approximations to the truth ; but, accepted as such, they are useful, as conveying some definite impression, of the influence of nitrogenous manures on carbon-assimilation, and on carbohydrate-formation.

As Table V. shows, the calculations are based on the average produce, by the different manures, of Wheat over 20 years, of Barley over 20 years, of Sugar-Beet over 3 years, of Mangel-Wurzel over 8 years, of Potatoes over 10 years, and of Beans over 8 years.

It is thus seen that, independently of the underground growth, the Wheat was estimated to assimilate 988 lbs. of carbon per acre per

annum, under the influence of a complex mineral manure alone; and that the amount was increased to 1,590 lbs. by the addition of 43 lbs. of nitrogen as ammonium-salts, to 2,222 lbs. by 86 lbs. of nitrogen as ammonium-salts, and to 2,500 lbs. by 86 lbs. nitrogen as sodium-nitrate. Accordingly, as shown in the second column, the increased assimilation of carbon was, by 43 lbs. of nitrogen as ammonium-salts 602 lbs., by 86 lbs. as ammonium-salts 1,234 lbs., and by 86 lbs. as sodium-nitrate 1,512 lbs.

TABLE V.

Estimates of the Yield and Gain of Carbon, and of the Gain of Carbohydrates, per acre per annum, in various Experimental Crops, grown at Rothamsted.

	Carbon.		Carbohydrates.	
	Actual.	Gain.	Gain.	For 1 Nitrogen in Manure.
WHEAT 20 years, 1852-1871.				
Mineral Manure	lbs. 988	lbs.	lbs.	lbs.
Mineral Manure and 43lbs. Nitrogen as Ammonia..	1590	602	1240	28.8
Mineral Manure and 86lbs. Nitrogen as Ammonia..	2222	1234	2550	29.7
Mineral Manure and 86lbs. Nitrogen as Nitrate ..	2500	1512	3140	36.5
BARLEY 20 years, 1852-1871.				
Mineral Manure	1138			
Mineral Manure and 43lbs. Nitrogen as Ammonia..	2088	950	1992	46.3
SUGAR-BEET 3 years, 1871-1873.				
Mineral Manure	1123			
Mineral Manure and 86lbs. Nitrogen as Ammonia..	2600	1477	3188	37.1
Mineral Manure and 86lbs. Nitrogen as Nitrate ..	3031	1908	4052	47.1
MANGEL WURZEL 8 years, 1876-1883.				
Mineral Manure	759			
Mineral Manure and 86lbs. Nitrogen as Ammonia..	1889	1130	2376	27.6
Mineral Manure and 86lbs. Nitrogen as Nitrate ..	2129	1370	2771	32.2
POTATOES 10 years, 1876-1885.				
Mineral Manure	1021			
Mineral Manure and 86lbs. Nitrogen as Ammonia..	1783	762	1507	17.5
Mineral Manure and 86lbs. Nitrogen as Nitrate ..	1752	731	1416	16.5
BEANS 8 years, 1862 and 1864-1870.				
Mineral Manure	726			
Mineral Manure and 86lbs. Nitrogen as Nitrate ..	992	266	474	5.5

Reckoned in the same way, the increased assimilation of carbon in the Barley was, for 43 lbs. nitrogen as ammonium-salts, 950 lbs. per acre; that is one-and-a-half time as much as by the same application in the case of wheat.

In the Sugar-Beet (the roots only), the increased assimilation of carbon was 1,477 lbs. per acre by the application of 86 lbs. nitrogen as

ammonium-salts, and 1,908 lbs. by 86 lbs. nitrogen as sodium-nitrate. There is, therefore, considerably more increased assimilation of carbon in the produce of Sugar-Beet than in that of Wheat by the same applications of nitrogenous manure.

In Mangel-Wurzel roots the increased assimilation of carbon was 1,130 lbs. by 86 lbs. of nitrogen as ammonium-salts, and 1,370 lbs. by 86 lbs. as nitrate; that is less than in the removed crops (corn and straw) of Wheat, and considerably less than in the removed crops (the roots) of Sugar-Beet.

In the case of the Potatoes, reckoned on the increased production of tubers only (the tops being left on the land), the increased yield of carbon by 86 lbs. of nitrogen as ammonium-salts is 762 lbs. per acre, and by 86 lbs. as sodium-nitrate 731 lbs. That is to say, there is considerably less increased production of starch in Potatoes, than of sugar in Sugar-Beet, or Mangel-Wurzel, by the same applications of nitrogenous manure.

Lastly, in the Leguminous crop, Beans, with its high yield of nitrogen per acre, and the high percentage of nitrogen in its dry substance, the increased assimilation of carbon under the influence of nitrogenous manure was comparatively quite insignificant. Thus, there was, by the application of 86 lbs. of nitrogen as sodium-nitrate, an increased assimilation of carbon of only 266 lbs. per acre; or little more than one sixth as much as in Wheat, and little more than one-eighth as much as in Sugar-Beet, by the same application.

Turning to the figures in the third column, it is seen that the estimated increased production of the non-nitrogenous carbohydrates, by the use of nitrogenous manures, was very great.

Thus, by the use of 43 lbs. of nitrogen as ammonium-salts, there is an estimated increase of 1,240 lbs. of carbohydrates in Wheat, and of 1,992 lbs. in Barley. By the application of 86 lbs. of nitrogen as ammonium-salts, there was an increased formation of carbohydrates of 2,550 lbs. in Wheat, of 3,188 lbs. in Sugar-Beet, of 2,376 lbs. in Mangel-Wurzel, and of only 1,507 lbs. in Potatoes; and when 86 lbs. were applied as sodium-nitrate, there was an increased production of 3,140 lbs. in Wheat, of 4,052 lbs. in Sugar-Beet, of 2,771 lbs. in Mangel-Wurzel, and of only 1,416 lbs. in Potatoes. Whilst, compared with these amounts, there was, by the same application, an increase of only 474 lbs. of carbohydrates in Beans.

The last column shows the estimated increased amounts of carbohydrates produced for 1 lb. of nitrogen in manure, in the different cases. Thus, when 43 lbs. of nitrogen were applied as ammonium-salts, 1 lb. of nitrogen in manure gave an increased production of 28.8 lbs. of carbohydrates in wheat, and of 46.3 lbs. in Barley; when 86 lbs. nitrogen were applied as ammonium-salts, 1 lb. gave an increase of 29.7 lbs. carbohydrates in Wheat, 37.1 lbs. in Sugar-Beet, 27.6 lbs. in Mangel-Wurzel, and 17.5 lbs. in Potatoes. Again, when 86 lbs. were applied as sodium-nitrate, 1 lb. gave an increase of 36.5 lbs. carbohydrates in Wheat, 47.1 lbs. in Sugar-Beet, 32.2 lbs. in Mangel-Wurzel, 16.5 lbs. in Potatoes, and only 5.5 lbs. in the Leguminous crop—Beans.

It is natural to ask—what is the explanation of the apparently anomalous result, that the crops which are characterised by containing comparatively little nitrogen, and by yielding large amounts of non-nitrogenous products—starch, sugar, and cellulose—are especially benefited by the application of nitrogenous manures; and that, under their influence, they yield greatly increased amounts of those non-nitrogenous bodies?

It is, perhaps, little more than stating the facts in another way to say, as is the case, that the luxuriance, or activity of growth, of all these crops, is very greatly enhanced by nitrogenous manures; and that, since their special products are these non-nitrogenous substances, the natural result of the increased luxuriance is to increase the formation of the bodies which are their essential or characteristic products.

A further possible explanation of the curious results has, however, been suggested.*

Thus, on purely chemical and physiological grounds, and, so far as would appear, without any special reference to the fact that, in the case of our chief starch and sugar yielding crops, the production of those substances is greatly enhanced by the use of nitrogenous manures, it has been suggested that the substance first formed in the chlorophyll-corpuscle, from carbon-dioxide and water, is not starch, but a substance possibly allied to formic aldehyde (CH_2O), which goes to construct proteid, by combining with the nitrogen and sulphur absorbed in the form of salts from the soil, or with the nitrogenous residues of previous decompositions of proteid. It is supposed, however, that starch may, nevertheless, be the first *visible* product of the constructive metabolism; since, unless protoplasm were being formed, no starch could be produced.

This view is partly founded on the consideration of the analogy that would then be established, between the formation of starch and that of the carbohydrate—cellulose; which is by some experimenters supposed to be derived directly from protoplasm.

It is true, that such a supposition is at any rate not inconsistent with the conditions which we have seen to be favourable for the increased production of starch and sugar in agricultural plants. At the same time, it is admittedly at present little more than hypothesis. It would, indeed, require more evidence than is at present available, to establish such a conclusion; whilst there are considerations which would lead us to hesitate to adopt the view in question, without clear experimental proof.

Thus, it seems difficult to suppose, that the undoubted connection in some striking cases, between the amount of nitrogen taken up by the plant, and the amount of starch or sugar formed, is to be explained by an assumption which implies that a chief office of the nitrogenous bodies of plants is to serve as intermediate only, in the transformations

* See Vines' Lectures on the "Physiology of Plants," p. 140, *et seq.*

necessary for the formation of the non-nitrogenous substances. The view does not, however, assume that nitrogen is eliminated from the plant in the process, and so lost.

Then, again, plants such as many of the Leguminosæ, which are characterised by assimilating relatively very large amounts of nitrogen over a given area of land, and by the formation of very large amounts of proteid in proportion to plant surface, produce relatively small amounts of the carbohydrates.

Nor is it irrelevant to refer to the fact that, from theoretical considerations, it was for many years assumed, especially in Germany, in opposition to the teachings of our own numerous direct experiments, that in the animal body the non-nitrogenous substance—fat—was mostly, if not always, produced by the degradation of proteid; the nitrogenous bye-products being for the most part, if not entirely, eliminated from the body as waste matter. It is, however, now indubitably established, at any rate in the cases of the *herbivora* which produce the most fat, that that substance is derived largely, if not exclusively, from the non-nitrogenous constituents of the food—the carbohydrates.

In the case of the supposed transformation in plants, the same prodigal expenditure of the nitrogenous bodies in the formation of the non-nitrogenous is, however, as has been said, not involved.

EFFECTS OF NITROGENOUS MANURES ON LEGUMINOUS CROPS.

Such are the very marked effects of nitrogenous manures in increasing the amounts of produce, and especially in increasing the production of non-nitrogenous constituents, when applied to our *non*-Leguminous, and comparatively low in nitrogen, crops. I have now to illustrate the influence of nitrogenous manures on various Leguminous crops, which, on the other hand, are characterised by containing a high percentage of nitrogen in their dry substance, and by assimilating a large amount of nitrogen from some source over a given area of land. It will be seen that the results to which I have to direct attention will bring to view some very remarkable failures, but also some not less signal and significant successes.

My first illustrations relate to experiments with Beans, grown for many years in succession on the same land—without manure, with a purely mineral manure (consisting of superphosphate of lime, and salts of potash, soda, and magnesia), also with the same mineral manure, and nitrogenous manure in addition, supplied either as ammonium-salts, or as sodium-nitrate. The results are recorded in Table VI. (p. 14).

It is seen that the record relates to a period of 32 years of continued or interrupted experiment with Beans, from 1847 to 1878 inclusive.

The first three columns show the produce of the corn, the second three that of the straw, and the third three that of the total produce, corn and straw together; each under three conditions as to manuring.

TABLE VI.

BEANS.

Grown year after year on the same land, Geescroft Field, Rothamsted.
Results, without Manure, with Mineral Manure, and with Mineral and Nitrogenous Manure.

Produce per acre, each year, in lbs.

Years.	Total Corn.			Total Straw.			Total Produce (Corn and Straw).		
	Unma- nured.	Mixed Mineral Manure (includ- ing Potash).	Mixed Mineral Manure and Ni- trogen. (1)	Unma- nured.	Mixed Mineral Manure (includ- ing Potash).	Mixed Mineral Manure and Ni- trogen. (1)	Unma- nured.	Mixed Mineral Manure (includ- ing Potash).	Mixed Mineral Manure and Ni- trogen. (1)
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1847	1611	1697	1748	2125	1969	2185	3796	3656	3931
1848	1380	1831	2048	1269	1592	1790	2659	3963	3778
1849	2173	(2390)	2250	1641	(2)	1743	3814	(2)	3993
1850	1071	1432	1679	1070	1312	1441	2141	2744	3120
1851	2074	3315	3554	1920	3279	3568	3994	6594	7122
1852	697	855	1007	820	1286	1541	1517	2141	2548
1853	280	462	555	489	802	992	749	1264	1547
1854	365	1428	1266	394	1272	1133	759	2695	2399
1855	987	956	889	770	828	788	1757	1784	1677
1856	755	1627	1568	808	1914	1900	1563	3541	3468
1857	732	660	648	676	644	636	1408	1304	1284
1858	126	640	612	654	1392	1300	780	2032	1912
1859	142	352	401	196	416	498	338	768	899
1860	Fallow								
1861 (3)	(2156)	(2434)	(2509)	(3869)	(4596)	(4742)	(6025)	(7030)	(7251)
1862	513	1014	1479	830	2256	3064	1443	3270	4543
1863	Fallow								
1864	193	1672	1837	960	2568	2468	1093	4240	4905
1865	261	514	1296	704	1080	2180	965	1594	3476
1866	142	316	914	317	628	1190	459	944	2104
1867	49	381	604	280	1252	1360	329	1633	1964
1868	48	394	478	538	930	1208	561	1314	1681
1869	106	926	1303	338	1394	1607	444	2320	2910
1870	458	450	615	516	483	593	974	933	1148
1871	Crop de	destroyed	by severe winter						
1872	Fallow								
1873	Fallow								
1874	1259	1899	2087	944	1328	1566	2203	3227	3655
1875	1193	882	1114	1674	1988	2576	2867	2870	3690
1876	Fallow								
1877	674	1974	1685	722	1809	1533	1396	3783	3218
1878	148	949	1108	301	1216	1496	449	2165	2604

Average per acre per annum, over each period of 8 years, and the total period of 32 years.

8 yrs., 1847-1854	1205	1573 (4)	1763	1216	1635 (4)	1792	2421	3208 (4)	3555
8 yrs., 1855-1862	676	960	1013	988	1506	1616	1664	2466	2629
8 yrs., 1863-1870	150	590	881	456	1042	1317	606	1622	2198
8 yrs., 1871-1878	409	713	749	455	793	897	864	1506	1646
32 yrs., 1847-1878	610	987 (5)	1102	779	1231 (5)	1405	1389	2168 (5)	2507

Average per acre per annum, over the years of crop only, each period.

1st 8 yrs., 8 crops	1205	1573 (6)	1763	1216	1635 (6)	1792	2421	3208 (6)	3555
2nd 8 yrs., 7 crops	773	1097	1158	1129	1721	1847	1902	2318	3005
3rd 8 yrs., 7 crops	171	663	1007	521	1191	1506	692	1854	2513
4th 8 yrs., 4 crops	819	1426	1499	910	1585	1793	1729	3011	3292
32 yrs., 26 crops	751	1162 (7)	1356	958	1526 (7)	1730	1709	2688 (7)	3086

(1) 5 years, 1847-1851, 46 lbs. Nitrogen as Ammonium Salts; 11 years, 1862, 1864-1870, 1875, 1876, and 1878, 86 lbs. Nitrogen as Sodium Nitrate. (2) Accidentally not weighed. (3) Wheat. (4) 7 years, excluding 1849. (5) 31 years, excluding 1849. (6) 7 crops, excluding 1849. (7) 25 crops, excluding 1849.

It should be further explained that, in the first 5 years, the nitrogen applied to the third plot was in the form of ammonium-salts. The effects were, however, so small and irregular, that the application of nitrogenous manure was then suspended for some years; indeed for 10 years, when, it having been observed that nitrates were more beneficial to Leguminosæ than ammonium-salts, sodium-nitrate was applied instead; in amount supplying 86 lbs. nitrogen per acre per annum, or nearly twice as much as had been given as ammonium-salts in the earlier years. This application of the nitrate commenced in 1862; and with some breaks, owing to severe or wet winters, which prevented the seed being sown, or destroyed the plant, it was continued up to 1878, when the experiments were finally abandoned.

Referring to the results, a glance at the Table shows that, independently of fluctuations obviously due to season, there were frequent entire failures, which were also more or less due to season, but which were also dependent partly on the conditions induced in the land by the continuous cropping with this plant; which, as is the case with most Leguminosæ, is very susceptible to parasitic attacks of various kinds, when the conditions of growth are not normal and favourable. Indeed, it is seen that, even when there was not absolute failure, there was a general tendency to decline in yield, and then to recover again, more or less, after a break. This was somewhat marked after a year of Fallow in 1860, and the growth of Wheat in 1861; after which there was, in 1862, fair produce, especially on the third plot, where the nitrate was now applied. The land was again Fallow in 1863, and this was again followed by improved growth; after which there was declining produce for a number of years to 1870 inclusive, and again recovery in 1874, after 3 years of Fallow. This general view of the results is of interest, as fixing attention on the great tendency to failure of this Leguminous crop, when grown year after year on the same land.

Turning to the effects of the different manures, it will suffice to direct attention to the last three columns of the Table, which record the amounts of total produce, that is corn and straw together, under each of the three conditions as to manuring.

Disregarding the results of the first year, when the unmanured plot gave relatively high produce, it is seen that, although there are irregularities, there is generally, whether the crops are large or small, a considerable increase of produce by the use of the mineral manure containing potash, but there is comparatively little further increase by the addition of nitrogenous to the mineral manure. Thus, as shown in the bottom division but one of the Table, the average annual total produce, over the 32 years (which however included 7 without any Bean crop) was—without manure, 1,389 lbs., with the mineral manure alone 2,168 lbs., and with the mineral and nitrogenous manure together 2,507 lbs. That is to say, whilst the mineral manure without nitrogen gave an average annual increase of 779 lbs., the addition to it of nitrogenous manure only further raised the produce by 339 lbs.

Or if, instead of taking the average of the 32 years, we take it only over the 26 years in which there was any Bean crop, the average total produce was—without manure 1,709 lbs., with purely mineral manure 2,688 lbs., and with the mineral and nitrogenous manure together, 3,086 lbs.; that is, there was an annual average increase of 979 lbs. by the mineral manure containing potash, and of only 398 lbs. more by the addition of nitrogenous manure.

The details further show that—without manure, the total produce of two of the last 8 years was only exceeded three or four times during the whole period, namely during the first five years;—with mineral manure alone, the total produce of 2 of the last 8 years was only exceeded four or five times;—and with the mineral and nitrogenous manure together, the total produce of 2 of the last 8 years was only exceeded six times. Indeed, on both of the manured plots, the average total produce over the last 4 years of actual crop, was nearly as much as the average of the first 8 years of crop. Thus, with the purely mineral manure, the average total produce of the first 8 years was 3,208 lbs., and over the last 4 years of crop it was 3,011 lbs., and with the mineral and nitrogenous manure, it was over the first 8 years 3,555 lbs., and over the last 4 years of crop 3,292 lbs. It will be seen further on, that the average annual yield of nitrogen was also nearly as great over the last 4 years, as over the first 8 years, of crop.

It may be observed that nitrogen supplied as ammonium-salts to the highly nitrogenous Leguminous crops, seldom gives any increase, and is sometimes injurious, in the year of application; though some benefit may afterwards result from the residue after the ammonia has been converted into nitric acid. Even nitrates, however, directly applied as manure, are very uncertain in their action, and at any rate yield very much less increase of produce with the highly nitrogenous Leguminosæ, than with the Gramineæ, and crops of other families, yielding produce of low percentage of nitrogen in its dry substance, and appropriating comparatively little nitrogen over a given area of land.

To this point I shall have to refer in some detail further on, but in the meantime it is to be specially noted, that whilst the Cereal crops may be successfully grown for many years in succession on the same land, provided only that mineral and nitrogenous manures are liberally supplied, the Leguminous crop—Beans, gradually fails when so grown; and although characteristically benefited by mineral manures containing potash, neither these alone, nor a mixture of mineral and nitrogenous manure, has sufficed to maintain even fair growth for a number of years in succession.

The result is, however, not entirely due to deficiency in the supply of constituents within the soil, but is also in a considerable degree dependent on the fact that, by the continuous growth of the crop, with its special habit, and range of roots, the surface soil acquires a close and unfavourable condition, and a somewhat impervious pan is formed below. The improved result in the later years, with the inter-

vention of Fallow, further illustrates the fact that the previous failures were not wholly due to exhaustion.

The next Table, VII. (below), shows the amounts of nitrogen in the Bean crops, the produce of which we have been considering.

TABLE VII.

BEANS.

Grown year after year on the same land, with different Manures, in Geescroft Field, Rothamsted.

Yield of Nitrogen, lbs. Average per acre, per annum, 8-year periods.

Periods.	In Corn.			In Straw.			In Total Produce (Corn and Straw).		
	Unma- nured.	Mixed Mineral Manure (includ- ing Potash).	Mixed Mineral Manure and Ni- trogen. (1)	Unma- nured.	Mixed Mineral Manure (includ- ing Potash).	Mixed Mineral Manure and Ni- trogen. (1)	Unma- nured.	Mixed Mineral Manure (includ- ing Potash).	Mixed Mineral Manure and Ni- trogen. (1)
Average per acre per annum, over each period of 8 years, and the total period of 32 years.									
8 yrs., 1847-1854	39.0	48.4 (2)	54.5	9.4	11.8 (2)	14.5	48.4	60.2 (2)	69.0
8 yrs., 1855-1862	18.3	24.4	26.5	7.0	9.9	10.3	25.3	34.3	36.8
8 yrs., 1863-1870	5.1	16.0	26.4	4.1	7.5	8.7	9.2	23.5	35.1
8 yrs., 1871-1878	13.0	21.2	22.3	3.4	5.5	6.4	16.4	26.7	28.7
32 yrs., 1847-1878	18.9	26.8 (3)	32.4	5.9	8.6 (3)	10.0	24.8	35.4 (3)	42.4
Average per acre per annum, over the years of crop only, each period.									
1st 8 yrs., 8 crops	39.0	48.4 (4)	54.5	9.4	11.8 (4)	14.5	48.4	60.2 (4)	69.0
2nd 8 yrs., 7 crops	20.9	27.9	30.3	8.0	11.3	11.8	28.9	39.2	42.1
3rd 8 yrs., 7 crops	5.8	18.3	30.1	4.6	8.5	9.9	10.4	26.8	40.0
4th 8 yrs., 4 crops	26.0	42.4	44.5	6.7	10.9	12.9	32.7	53.3	57.4
32 yrs., 1847-1878 } 26 crops	23.2	33.3 (5)	39.9	7.3	10.6 (5)	12.3	30.5	43.9 (5)	52.2

(1) 5 years, 1847-1851, 46 lbs. Nitrogen as Ammonium Salts; 11 years, 1862, 1864-1870, 1875, 1876, and 1878, 86 lbs. Nitrogen as Sodium Nitrate. (2) 7 years, excluding 1849. (3) 31 years, excluding 1849. (4) 7 crops, excluding 1849. (5) 26 crops, excluding 1849.

GENERAL NOTE.—In the second 8 years, the land was fallow in 1860, and wheat was grown in 1861; in the third 8 years, 1863 was fallow; and in the fourth 8 years, the crop failed in 1871, and the land was left fallow in 1872, 1873, and 1876.

The Table is on the same plan as that relating to the produce, but instead of results for every year of the 32, there are now given only averages, in the upper division for the four 8 yearly periods, and for the total period of 32 years; and in the lower division for the years of crop only, within each period. As in Table VI., the first three columns give for each of the three conditions as to manuring, the results for the corn, the second three for the straw, and the last three for the total produce, corn and straw together. It will suffice to direct attention to these last results.

Referring to the figures in the upper division, it may be observed that, notwithstanding there were 6 blank years, and 1 year of wheat, out of the 32, and notwithstanding that the produce declined much, and gave on the whole much less than the average obtained under ordinary agricultural conditions, yet the average yield of nitrogen in the

crops grown without any supply of it was much more than in either of the Cereals, the Root-crops, or Potatoes, grown under similar conditions.

Thus, as the bottom line of the upper division shows, there was an average, over the 32 years, of 24.8 lbs. of nitrogen, per acre per annum, in the crops without any manure, but of 35.4 lbs. with the mineral manure without nitrogen; whilst the amount was raised to only 42.4 lbs. by the addition of nitrogenous manure. Over the first 8 years, however, the yield was very much higher, being for the three plots, respectively, 48.4, 60.2, and 69.0 lbs. Over the second period of 8 years the average was not far from that of the whole 32 years; but over the third and fourth periods it was much less.

As in the case of the total produce itself, so also in that of the nitrogen in the total produce, if we take the averages of the years of crop only, as given in the bottom division of the Table, we have a much higher average yield per annum over the 4 years of crop of the last 8 years, than over the years of crop of either the second or the third period of 8 years. Indeed, on the two manured plots, there is an average annual yield of nitrogen per acre, over the 4 years of crop during the last 8 years, not far short of the average of the first 8 years. Thus, with the purely mineral manure, there is an average annual yield of nitrogen over the first 8 years of 60.2 lbs., and over the 4 years of crop of the last 8 years, of 53.3 lbs.; and with the mineral and nitrogenous manure together, over the first 8 years, of 69.0 lbs., and over the 4 years of crop of the last 8 years, of 57.4 lbs.

That is, with the intervention of Fallow, we have, though not good agricultural crops, yet really large yields of nitrogen, compared with those obtained in many of the preceding years; and very large yields without any supply by manure, compared with those obtained under the same conditions with any of the *non*-Leguminous crops. It would appear probable, therefore, that if a suitable mechanical condition of the land could have been maintained, fair crops, and large yields of nitrogen, would also have been maintained.

Upon the whole, then, although the crop practically failed, when it was attempted to grow it year after year on the same land, it nevertheless accumulated, in its above-ground produce, much more nitrogen over a given area than the crops of the other families; but was little benefited by an artificial supply of nitrogen.

I have now to record a still greater failure, with another crop of the Leguminous family—namely, *Trifolium pratense*, or Red Clover. The results are summarised in Table VIII. (p. 19).

The Table is headed Red Clover sown frequently on the same land; and the first column shows that the period of experiment was 29 years, from 1849 to 1877 inclusive. But the details show that, although Clover was sown 15 times, in only 7 of the 29 years was any Clover-crop obtained; whilst about one-fifth of the produce of the whole series of years was yielded in the first year, 1849. It is, indeed, well known in agriculture, that Clover will not grow, under ordinary conditions, more

frequently than once in a certain number of years, which varies according to soil and other circumstances, but is seldom so few as four, and frequently as much as 8 years.

TABLE VIII.
RED CLOVER.

Sown frequently on the same land, in Hoosfield, Rothamsted.
Total Produce, per acre per annum; Clover as Hay, other Crops Corn and Straw together.

Year.	Description of Crop.	SERIES 1. Mineral Manure alone.	SERIES 2. Mineral and Nitrogenous Manures.
1849	Clover	lbs. 10214	lbs. 10326
1850	Wheat	(6261)	(6345)
1851	Clover	2309	2368
1852	Clover	5895	4914
1853	Clover	No crop.	No crop.
1854	Fallow		
1855	Clover	1281	2606
1856	Fallow		
1857	Fallow		
1858	Barley	(6598)	(7678)
1859	Clover	2752	3087
1860	Clover	No crop.	No crop.
1861	Fallow		
1862	Barley	(5745)	(6730)
1863	Fallow		
1864	Clover	No crop.	No crop.
1865	Clover	2467	4500
1866	S. 1 Clover, S. 2 Barley ..	No crop.	(2974)
1867	Fallow		
1868	Clover	No crop.	No crop.
1869	Clover	No crop.	No crop.
1870	Barley	(3328)	(3312)
1871	Clover	No crop.	4085
1872	Fallow		
1873	Fallow		
1874	Clover	No crop.	Fallow.
1875	Clover	4277	Fallow.
1876	Fallow		
1877	Barley	(1864)	(1864)

SUMMARY. PRODUCE.

29 years, 1849-1877..	{	Total.. .. .	52991	60689
		Average	1827	2093
Years of Crop only..	{	Average	4416	4668
Years of Clover only (7) ..	{	Total.. .. .	29196	31886
		Average	4171	4555

SUMMARY. NITROGEN (Estimated).

29 years, 1849-1877..	{	Total.. .. .	929.4	1043.1
		Average	32.0	36.0
Years of Crop only..	{	Average	77.5	80.2
Years of Clover only (7) ..	{	Total.. .. .	700.7	765.3
		Average	100.1	109.3

The second column shows that, owing to the failure of the Clover, sometimes a cereal crop, Wheat or Barley, was sown; but more frequently the land was left Fallow. The produce of Wheat, or of Barley, is given between brackets.

The amounts of produce entered in the column headed Series 1, are, in each case, the means of those on 3 plots, each of which occasionally received a mineral manure containing potash; and the results given in the column, Series 2, are also the means of 3 plots, each with the mineral, and nitrogenous manures in addition, occasionally applied.

It is seen that very large crops of Clover were obtained in the first year, 1849; less than one-quarter as much in the third year, 1851; and in the fourth year about half as much as in the first. There was then no more Clover until the seventh year, when there was very little. More or less was afterwards obtained in the eleventh, seventeenth, twenty-third (on one plot), and lastly (on one plot) in the twenty-seventh year; but, in no case excepting in the fourth year, was the amount of produce half as much as in the first year.

Comparing the results without, and with, the nitrogenous manure, it is shown, in the summary at the bottom of the Table, that the average annual total produce, of Clover-hay, or of other crops, was, reckoned over the 29 years, 1827 lbs. without, and 2093 lbs. with, the nitrogenous manure; and, reckoned in the same way, the average annual yield of nitrogen was, without nitrogenous manure 32 lbs., and with it 36.0 lbs. Reckoned, however, over the years of crop only, the yield of nitrogen in the Clover and other crops, was, 77.5 lbs. per acre per annum without, and 80.2 lbs. with, the nitrogenous manuring. Or, reckoning the nitrogen in the Clover alone, and only over the years when it gave any crop, the average annual yield of it over those 7 years was, without nitrogenous manure 100.1 lbs., and with it, 109.3 lbs. There was, therefore, comparatively little increase, either in the produce, or in the yield of nitrogen, by the use of nitrogenous manures.

To conclude in regard to these experiments:—The attempt to grow Clover year after year on ordinary arable land, by means of such mineral manures as increase the luxuriance of growth when there is a fair plant, or even by the addition to these of nitrogenous manures, has entirely failed. In view of this failure to grow the crop continuously on ordinary arable land, the next results to which I have to call attention are of much interest and significance.

GROWTH OF RED CLOVER, YEAR AFTER YEAR, ON RICH GARDEN SOIL

In 1854, after it seemed clear that the plant would not continue to grow on the arable land, Clover was sown in a garden, only a few hundred yards distant from the experimental field, on soil which had been under ordinary kitchen-garden cultivation for probably two or three centuries. It is remarkable that, under these conditions, the crop has grown luxuriantly almost every year since; this year, 1889, being the 36th season of the continuous growth. Further particulars

will be given on the point presently, but it may here be premised that, at the commencement, the percentage of nitrogen in the surface soil of the garden was at least four times as high as in that of the arable soil in the field, and it would doubtless be richer in all other matters also. Indeed, it is probable that the subsoil of the garden, below the first 9 inches of depth, would be as rich, and perhaps richer than the surface soil of the field. Table IX. (below), gives the results for 35 of the 36 years of experiment with Clover on the rich garden soil.

TABLE IX.
RED CLOVER.

Grown year after year on Rich Garden-soil, The Garden, Rothamsted.
Hay, Dry Matter, Mineral Matter, and Nitrogen, per acre, per annum.

Years.	Number of Cuttings.	As Hay.	Dry Matter.	Mineral Matter.	Estimated Nitrogen.	Dates of Sowing Seed.
		lbs.	lbs.	lbs.	lbs.	
1854	2	5,191	4,826	435.0	124.6	1854, March 29.
1855	3	18,113	15,094	1560.0	434.7	
1856	2	11,027	9,190	1115.5	264.6	
1857	3	14,855	12,379	1384.0	356.5	
1858	2	7,608	6,340	792.0	182.6	
1859	2	6,227	5,189	686.5	149.4	1860, May.
1860	1	8,679	7,253	806.0	208.3	
1861	2	13,353	11,128	1225.0	320.5	
1862	2	10,042	8,368	990.5	241.0	
1863	2	11,798	9,832	971.0	253.2	
1864	2	5,500	4,588	446.0	132.0	1865, April 22.
1865	1	2,044	1,704	189.5	49.1	
1866	2	10,456	8,713	907.5	250.9	
1867	2	6,748	5,624	573.0	162.0	
1868	1	991	826	106.0	23.8	
1869	2	4,188	3,496	387.0	100.4	1868, April 29.
1870	1	1,741	1,451	148.0	41.8	
1871	1	4,513	3,761	458.0	108.8	
1872	2	10,142	8,452	898.5	243.4	
1873	2	9,287	7,740	772.0	222.9	
1874	3	5,899	4,916	539.5	141.6	1874, May 4, and July 7.
1875	1	2,731	2,276	229.5	65.5	
1876	2	3,517	2,931	278.5	84.4	
1877	1	3,533	2,944	325.5	84.8	
1878	3	13,416	11,190	1335.5	322.0	
1879	1	2,738	2,282	427.5	65.7	1879, May 21.
1880	2	5,742	4,785	643.0	137.8	
1881	2	4,262	3,552	330.0	102.3	
1882	3	6,433	5,361	641.0	154.4	
1883	1	2,716	2,264	314.5	65.2	
1884	3	9,990	8,325	862.5	239.8	1886, April 14.
1885	3	6,511	5,426	615.0	156.3	
1886	1	2,702	2,252	313.0	64.8	
1887	2	3,237	2,739	284.0	78.9	
1888	1	1,841	1,535	210.5	44.2	

SUMMARY. Averages.

10 years, 1854-'63	10,889	8,908	1002.5	256.5
10 years, 1864-'73	5,561	4,684	488.6	133.4
10 years, 1874-'83	5,099	4,249	506.5	122.4
5 years, 1884-'88	4,866	4,055	453.0	116.8
35 years, 1854-'88	6,795	5,663	635.4	163.1

The first column after the dates, shows the number of cuttings each year, the second the amounts of produce per acre, reckoned in the condition of dryness as hay, the third the amount of dry substance, the fourth that of the mineral matter, and the last the estimated amounts of nitrogen per acre in the crops. At the bottom of the Table are given the average annual results over periods of 10, 10, 10, 5, and 35 years. I shall confine attention to the amounts of produce reckoned as hay, and to the estimated amounts of nitrogen in the produce.

It should be stated that, as the garden-clover plot is only a few yards square, calculations of produce per acre can only give approximations to the truth; but it is believed that they can be thoroughly relied upon so far as their general indications are concerned. It may be added that five times during the whole period, gypsum has been applied to one-third, and a mineral manure containing potash, but no nitrogen, to another third of this plot.

Casting the eye down the column of produce as hay, it is seen at a glance that, excepting a few occasional years of very high produce during the later periods, the amount of crop is very much greater during the first, than during either of the subsequent periods of 10 or 5 years. In fact, as is seen at the foot of the Table, there was an average annual produce equal to 10,689 lbs. of hay, over the first period of 10 years, but of only 5,561 lbs. over the second, and 5,099 lbs. over the third, and of only 4,866 lbs. over the last 5 years.

Now, even these latter amounts correspond to what would be considered fair, though not large crops, when Clover is grown in an ordinary course of rotation, once only in 4, or in 8 years, or more; so that the produce in the earlier years on this rich garden-soil, was very unusually large. Indeed, the average annual produce over the whole period of 35 years, namely 6,795 lbs.—more than 3 tons of hay—would be a very good yield for the crop grown only occasionally in the ordinary course of agriculture.

But it is when we look at the figures in the last column of the Table, which show the estimated amounts of nitrogen in the crops, that the importance and significance of these results obtained on rich garden-soil, are fully recognised; and this is especially the case when they are compared with those obtained on ordinary arable land.

Thus, whilst the amount of nitrogen in average crops of Wheat, Barley, or Oats, will be from 40 to 50 lbs. per acre, of Beans about 100 lbs., of Meadow Hay about 50 lbs., and Clover Hay grown occasionally in rotation little more than 100 lbs.;—here, on this rich garden-soil, the produce of Clover has, in one year contained more than 400 lbs. of nitrogen, in three years more than 300 lbs., in several more than 200 lbs., and in only eleven years of the 35 less than 100 lbs.

In fact, as the figures at the bottom of the Table show, the estimated average annual yield of nitrogen in the above-ground growth was—over the first 10 years 256 lbs., over the second 10 years 133 lbs., over the third 10 years 122 lbs., over the last 5 years 117 lbs., and over the whole period of 35 years 163 lbs.; whilst, as the details show, the

yield in the 31st year (1884) was about 240 lbs., and in the 32nd year 156 lbs. of nitrogen.

Further, the average over the third 10 years of the continuous growth (122 lbs.), was about as much as in a fair average crop grown occasionally under the ordinary conditions of agriculture.

There would seem, then, to be clearly indicated, a soil source of failure on the arable-land, and a soil source of success on the garden-soil.

The results given in Table X. (below) will throw some further light on this point. It shows the percentage of nitrogen in the first 9 inches of depth of the garden-soil, in 1857 and in 1879, between which periods the growth of 21 years had been removed.

It also shows the estimated amounts of nitrogen per acre in the surface soil at the two periods, and the reduction in the amount during the 21 years.

TABLE X.

RED CLOVER.

Grown on Rich Garden Soil.

Nitrogen, per cent. and per acre, in the fine soil, dried at 100° C.
(First 9 inches of depth).

	1857.	1879.	Difference.
	Per cent.	Per cent.	Per cent.
	0.5095	0.3634	0.1461
	lbs.	lbs.	lbs.
Per acre Total ..	9,528	6,796	2,732
Per acre per annum (21 years)			130

It may be mentioned, that the percentage of nitrogen given for the sample collected in October, 1857, is the mean of duplicate or more determinations, made in 1857, in 1866, and again in 1880; and it is almost identical with the results obtained at the latest of these dates.

The first point to notice is, that the first 9 inches of depth of this rich garden-soil contained more than half a per cent. of nitrogen; that is, nearly four times as much as the average of the Rothamsted arable soils, and nearly five times as much as the exhausted arable Clover-land soil where the crop failed. It is, of course, true, that the garden-soil would be correspondingly rich in all other constituents; but some portions of the arable soil where the Clover failed, had received much more of mineral constituents by manure than had been removed in the crops.

The result given for 1879 is the mean of determinations made on three separate samples, for which the determinations agreed very well. The results can leave no doubt that there had been a great reduction in the stock of nitrogen in the surface-soil since 1857. The reduction amounts to nearly 29 per cent. of the whole in the 21 years; and, reckoned per acre, as shown in the bottom line of the Table, it corresponded to a loss of 2,732 lbs. during the 21 years; and, although, as

has been seen, fairly average, and even good crops, were still grown, it is obvious that coincidently with this great reduction in the stock of nitrogen in the surface-soil, there has been a very marked reduction in the Clover-growing capability of the soil.

On this point it may be mentioned that, whilst fresh seed was only sown four times during the first 17 of the 35 years, it has been fully or partially sown 16 times during the last 18 years. It is obvious, therefore, that the plant was able to stand very much longer in the earlier than in the later condition of the soil. Indeed, both the reduced persistence of the plant, and the reduced produce, have been coincident with a considerable reduction in the stock of nitrogen in the soil.

The question arises—what relation does the amount of nitrogen lost by the soil, bear to the amount taken off in the crops?

It is admittedly necessary to accept with some reservation results of calculations of produce per acre, from amounts obtained on a few square yards, but the general indications may doubtless be trusted. Such estimates show more than 160 lbs. of nitrogen to have been removed per acre per annum in the crops, over the 21 years; whilst the estimated loss of the surface-soil corresponds to about 130 lbs. per acre per annum. That is to say, the loss by the surface-soil is sufficient to account for rather more than three-fourths of the amount of nitrogen removed in the crops.

There is, however, evidence leading to the conclusion that, in the case of soils to which excessive amounts of farmyard manure are applied, as, for instance, to such a garden soil, there may be some loss by the evolution of free nitrogen; and obviously so far as this may have occurred in the garden soil, there will be the less of the ascertained loss to be credited to assimilation by the growing Clover.

On the other hand, it is known that when growing on ordinary arable soil, the Clover plant throws out a large amount of feeding root in the lower layers; and although in the case of so rich a surface soil the plant may derive a larger proportion of its nutriment from that source, we must at the same time suppose that it has also availed itself of the resources of the subsoil. Unfortunately, in 1857 samples were only taken to the depth of nine inches, so that no comparison can be made of the condition of the subsoil at the two periods. It may be observed, however, that in 1879 the second nine inches showed about three times as high a percentage of nitrogen as the subsoils of the arable field at the same depth; indeed nearly twice as high a percentage as some of the exhausted arable surface-soils. It cannot be doubted, therefore, that the subsoil of the garden plot has contributed nitrogen to the Clover crops.

Here then, notwithstanding the very little effect of direct nitrogenous manures, on either the Beans or the Clover, on the ordinary arable land, there would seem to be very clear evidence of a soil-source of, at any rate much, if not indeed of the whole, of the enormous amounts of nitrogen assimilated over a given area by the Clover growing on the rich garden soil.

PRODUCE OF NITROGEN IN THE MIXED HERBAGE OF GRASS LAND.

The results in Table XI. afford evidence in the same direction.

TABLE XI.

EXPERIMENTS ON THE MIXED HERBAGE OF PERMANENT GRASS LAND.

The Park, Rothamsted.

Results showing the effects of Potash, on the development of Leguminosæ, and on the yield of Nitrogen in the crops.

Plots.	Conditions of Manuring.	Mean per cent. according to botanical separations at 6 periods, 1862, '67, '71, '72, '74, '75.			Average produce per acre per annum, 20 years, 1866-'75, according to mean per cent. of the 6 separations.			Average Nitrogen per acre per annum.		
		Gram-ineæ.	Legum-ineæ.	Other Orders.	Gram-ineæ.	Legum-ineæ.	Other Orders.	10 years 1866-1875.	10 years 1866-1875.	20 years 1866-1875.
		p. c.	p. c.	p. c.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
3	Unmanured	70·94	8·17	20·89	1690	195	498	35·1	30·9	33·0
4-1	Superphosphate*	68·17	5·68	28·15	1699	142	652	35·7	31·6	33·6
8	Complex Min. Man.†	73·71	8·43	17·86	2489	285	603	54·4	38·5	46·5
7	Complex Min. Man.‡	66·92	19·13	13·95	2649	757	552	55·2	58·0	56·6

* Plot 4-1, botanical separations at 4 periods only, namely 1862, 1867, 1872, and 1875.

† Including Potash, 6 years, 1866-61, excluding Potash, 14 years, 1862-1875.

‡ Including Potash every year.

As stated in the title of the Table, the results show, in the case of experiments on the mixed herbage of grass-land, the effects of potash on the development of the Leguminosæ, and on the yield of nitrogen in the crop. Results are given for four plots—one without any manure; one with superphosphate of lime alone; one with a complex mineral manure, including potash for six years, but excluding potash for the succeeding 14 years; and lastly, one with the complex mineral manure, including potash every year of the twenty.

The first set of three columns shows the average percentage of gramineous, leguminous, and miscellaneous herbage, in the produce, according to botanical separations made in six, or in four seasons, as stated; the second set the average produce per acre over 20 years, of each of these descriptions of herbage; and the last three columns show the amounts of nitrogen, per acre per annum, in the mixed produce, over the first 10, the second 10, and the total period of 20 years.

It is seen that on plot 8, with only a temporary supply of potash, the percentage of leguminous herbage in the produce is higher than on plot 4-1 with superphosphate of lime alone; but that, on plot 7, with the continuous supply of potash, it is more than twice as high. Thus, the percentage of leguminous herbage is—on plot 4-1, 5·68; on plot 8, 8·43; but on plot 7, 19·13.

The middle column of the second division shows that the estimated amounts of leguminous herbage per acre per annum were—on plot 4-1 without any potash 142 lbs., on plot 8 with partial supply of potash 285 lbs., and on plot 7 with the continuous supply 757 lbs.

Turning to the yield of nitrogen on the different plots, it is seen that the amounts are almost identical without manure, and with superphosphate of lime alone, namely, about 33 lbs. per acre per annum. On plot 8, where a complex mineral manure, including potash six years, but excluding it fourteen years, was employed, the yield of nitrogen is raised to 46·5 lbs.; and on plot 7, which received the mixed mineral manure, including potash every year of the twenty, the yield is 56·6 lbs. per acre per annum. Further, without manure, and with superphosphate of lime alone, there was a decline in the yield of nitrogen in the later, compared with the earlier years. With the mineral manure, including potash in the first six years only, there was a much more marked decline. With the mineral manure, including potash every year, there was, on the other hand, even a slight tendency to an increased yield of nitrogen, in the later years.

Thus, then, it is estimated that the plot receiving potash every year, yielded over a period of twenty years, an average of 23·6 lbs. more nitrogen per acre per annum than the unmanured plot, and this increased yield was associated with an increased growth of Leguminous herbage. Whence comes the 23·6 lbs. more nitrogen annually taken up per acre on the mineral manured than on the unmanured plot? The results in Table XII. will afford evidence on this point.

TABLE XII.
PERMANENT MEADOW LAND SOILS.

Nitrogen, per cent. and per acre, in fine soil, dried at 100° C.

	1870.	1876.	1878.
	Per cent.	Per cent.	Per cent.
Plot 3. Unmanured	0·2617	0·2466	
Plot 7. Mixed Mineral Manure, including Potash ..		0·2236	0·2246
Difference		0·0230	
		lbs.	
Difference per acre { Total 20 years		506·0	
{ Average per annum		25·3	

After 20 years of continuous experiment, samples of soil were taken at three places on each of the experimental plots, and the Table shows the means of determinations of nitrogen in the surface-soils of the unmanured plot, and of the plot receiving the complex mineral manure (including potash), every year. Some control results are also given. Thus, determinations made in samples of the unmanured soil collected in 1870, control those in the samples collected in 1876, after the crops of five more years had been removed; and, again, the results obtained on samples collected from the mineral manured plot in 1878, control and confirm those obtained on the samples taken in 1876.

Referring to the main figures, those relating to the samples taken in 1876, it is seen, that whilst the percentage of nitrogen in the surface-soil of the unmanured plot was 0·2466, it was in that of the mineral

manured plot, which had yielded so much more nitrogen in the crops, only 0·2236 per cent., or nearly one-tenth less.

Calculated per acre, the surface-soil of the mineral manured plot, to the depth of nine inches, contained, at the end of the twenty years, 506 lbs. less nitrogen than that of the unmanured plot to the same depth ; corresponding to an annual reduction of 25·3 lbs. per acre per annum.

Without pretending to claim absolute accuracy for such results, and such calculations, it is, to say the least, a very remarkable coincidence, that whilst the estimated increased yield of nitrogen per acre per annum, in the mineral manured crop was 23·6 lbs., the estimated increased loss of nitrogen by the surface soil should be 25·3 lbs. per acre per annum.

In reference to the fact that, according to the results, the resources of the surface soil would seem to have been mainly, if not wholly, drawn upon, it should be observed, that the potash of artificial manures is almost exclusively retained in the superficial layers of the soil, and that the leguminous plant that was the most prominently developed was the *Lathyrus pratensis*, which, although it has also deep roots, throws out an enormous quantity of feeding root near the surface ; whilst the prominent plants of other families were also those characterised by superficial rooting.

Here, again, then, in these results with the mixed herbage of grass land, as in those with the Clover on the rich garden-soil, there seems to be clear indication that the soil is an important source of nitrogen to Leguminosæ.

The next illustrations will bring to view the curious result that, on soil where one leguminous plant has practically failed, another plant of the same family may grow luxuriantly, and in some way obtain very large amounts of nitrogen.

RED CLOVER GROWN AFTER BEANS.

The experiments to which I have now to direct attention, were made in the field which had been devoted to experiments on the growth of beans for a period of 32 years ; but which, as has been seen, so far failed that an average crop was seldom obtained ; whilst the amount of nitrogen taken up over a given area, though still much more than in *non-Leguminous* crops grown under similar conditions, was, after the first few years, much below the amount in a fairly average Bean-crop. After the cessation of the experiment with Beans in 1878, the land was left fallow for between four and five years, to 1882 inclusive, when Grass-seeds were sown, but failed. On this land, on which the attempt to grow the Leguminous-crop—*Beans*—had been abandoned, Barley and Clover were sown in the spring of 1883.

Before considering the results of this new experiment, it will be well briefly to call attention to the direct experimental evidence as to the condition of the soils. Thus, in April, 1883, before the Barley and Clover were sown, the surface-soil (free of stones, and reckoned

dry) of the plot which had been entirely unmanured during the 32 years of the experiments with the Beans, contained 0·0993 per cent. of nitrogen, that of the mineral manured plot 0·1087 per cent., and that of the plot which had received both the mineral and nitrogenous manure 0·1163 per cent., amounts which show considerable nitrogen exhaustion of the surface-soil.

Also in 1883, the nitrogen as nitric acid was determined in samples, each of 9 inches of depth, down to a total depth of 72 inches. In the case of several plots, the results show, calculated per acre, that the total amount of nitrogen as nitric acid to the depth of 8 times 9 inches, or 72 inches in all, was 27·95 lbs. in the unmanured plot, 20·72 in that with purely mineral manure, and 25·38 lbs. in that of the plot which had received both mineral and nitrogenous manure. In the soil of the farm-yard manure plot, on the other hand, the amount was about twice as much—namely 50·46 lbs. Excluding this last result, it may be said that the amounts of nitrogen already existing as nitric acid, to the depth determined, were very small.

These, then, were the conditions of the soil when the Barley and Clover were sown in the spring of 1883. The Clover grew very luxuriantly from the first, so much so as considerably to interfere with the growth of the Barley.

Table XIII. (below), shows the amounts of nitrogen per acre in the Barley and Clover in 1883, and in the Clover in 1884 and 1885.

TABLE XIII.
BARLEY AND CLOVER, GROWN AFTER BEANS.
Geescroft Field.

Nitrogen removed per acre in the Crops.

Previous Condition of Manuring.	1883. Barley and Clover.	1884. Clover.	1885. Clover.	Total.
Without Manure	lbs. 45·0	lbs. 183·2	lbs. 52·7	lbs. 280·9
Mineral Manure and some Nitrogen	57·2	193·1	79·9	330·2
Mineral Manure only	59·3	206·4	81·6	347·3

It should be stated that the plots, the yield of nitrogen of which is here given, do not exactly correspond with those for which the yield of nitrogen in the Beans was given; some of the Barley and Clover crops having been taken together where no difference in the produce was observable. Thus, half the plot represented as without manure, had been unmanured from the commencement, that is for nearly 40 years, but the other half received some nitrogen to 1878 inclusive, but had since been entirely unmanured. Again, the results given in the second line relate to the produce of a plot part of which received purely mineral manure, but the other part ammonium-salts or nitrate up to 1878, but none since. The results given in the third line relate, however, to a plot which has not received any nitrogenous manure from the commencement of the experiments with the Beans, but which

was not brought under experiment until 5 years later than the other plots.

Thus, on a plot where a purely mineral manure containing potash, but no nitrogen, had been applied for 27 years, to 1878 inclusive, and no manure since, 347.3 lbs. of nitrogen were gathered per acre, almost wholly by the Leguminous crop—Clover. On a plot on part of which the mineral only, and on part the same mineral manure and ammonium-salts or nitrate had been applied up to 1878, but nothing since, 330.2 lbs. of nitrogen were removed in the crops. Lastly, where, to half of the plot no manure whatever had been applied for nearly 40 years, but to the other half ammonium-salts or nitrate had been applied up to 1878, the yield of nitrogen in the Barley and Clover was 280.9 lbs.

Here, then, in a field where Beans had been grown for many years in succession, and had yielded much less than average crops, and the land had then been left fallow for several years; where the surface-soil had become very poor in total nitrogen; where both surface and sub-soil were very poor in ready-formed nitric acid; and where there was a minimum amount of crop residue near the surface for decomposition and nitrification, there were grown very large crops of clover, containing very large amounts of nitrogen.

Not only was so much nitrogen removed in the crops, but the surface-soils became determinably richer in nitrogen, as the results in Table XIV. (below) show. There are there given, the percentages of nitrogen in the sifted dry surface-soil of the three plots for which the produce and the nitrogen in the Beans have been given. The results relate to samples taken in April 1883, before the sowing of the Barley and Clover, and in November 1885, after the removal of the crops. The first two columns show the percentages of nitrogen, and the other columns the calculated amounts of nitrogen per acre, in the surface-soils, 9 inches deep, at the different dates, and the estimated gain of nitrogen under the influence of the growth of the clover.

TABLE XIV.

Nitrogen, per cent. and per acre, in the surface-soils, before and after the growth of the Barley and Clover.

	Nitrogen in sifted dry soil.				
	Per cent.		Per acre.		
	1883.	1885.	1883.	1885.	1885 + or - 1883.
	Per cent.	Per cent.	lbs.	lbs.	lbs.
1. Without Manure	0.0993	0.1083	2441	2662	+ 221
2. { With Mineral Manure containing Potash }	0.1087	0.1149	2672	2824	+ 152
3. { With Mineral Manure and Nitrogen }	0.1163	0.1225	2859	3011	+ 152

Without assuming that the figures represent accurately the amounts of nitrogen accumulated per acre, it cannot be doubted that the

surface-soils had become considerably richer. If, for the sake of illustration, we assume that 300 lbs. of nitrogen were removed per acre in the crops, and that 150 lbs. were accumulated in the surface-soil, we have 450 lbs. of nitrogen to account for, as gathered by the crops within a period of little more than two years.

It is clear that we have in the experimental results themselves no conclusive evidence as to the source of so large an amount of nitrogen. As the surface-soil became determinably richer, it is obvious that it must have been derived either from above or below it—from the atmosphere, or from the sub-soil; and, if from the sub-soil, the question arises—whether it was taken up as nitric acid, as ammonia, or as organic nitrogen? I shall have to adduce evidence bearing on these points further on; but it must be admitted that there is nothing in the experimental results themselves, to show that so large an amount of nitrogen could have been available as nitric acid.

VARIOUS LEGUMINOUS PLANTS GROWN AFTER RED CLOVER.

I have now to adduce another, and even much more striking instance, of successful growth, and of great accumulation of nitrogen, by plants of the Leguminous family, on soil where another plant of the same family had failed, and where the surface-soil had become very poor in nitrogen.

The experiments were made on the plots where it had been attempted to grow Red Clover year after year on the same land; where, in fact, Clover had been sown 12 times in 30 years, and where, in 8 out of the last 10 trials, the plant had died off in the winter and spring succeeding the sowing of the seed; in 4 cases without any crop at all, and in the other 4 yielding very small cuttings.

In 1878, the land was devoted to experiments with various Leguminous plants, differently manured, having regard, however, to the previous manurial history of the plots.

The object was to ascertain whether, among a selection of plants all belonging to the Leguminous family, but of different habits of growth, and especially of different character and range of roots, some could be grown successfully for a longer time, and would yield more produce, containing more nitrogen, as well as other constituents, than others; all being supplied with the same descriptions and quantities of manuring substances, applied to the surface-soil. Further, whether the success in some cases, and the failure in others, would afford additional evidence as to the source of the nitrogen of the Leguminosæ generally, and as to the causes of the failure of Red Clover when grown too frequently on the same land.

Accordingly, 14 different *Leguminosæ* were selected, and sown in 1878. These included 8 species or varieties of *Trifolium*, 2 species of *Medicago*, *Melilotus leucantha*, *Lotus corniculatus*, *Vicia sativa*, and *Lathyrus pratensis*. Of these, 6 of the 8 *Trifoliums* have already failed, and been replaced by other plants; as also have the *Medicago*

lupulina, the *Lotus corniculatus*, and the *Lathyrus pratensis*; the last being replaced in the second year by *Onobrychus sativa*. The plants which have maintained fair, but very varying character of growth, are the *Trifolium repens*, *Vicia sativa*, *Melilotus leucantha*, and *Medicago sativa*; and I propose to give some account of the growth of these plants on this Clover-exhausted soil.

That the surface-soil had become very poor in nitrogen is evident from the fact, that the mean percentage of it in the sifted dry surface-soil of 5 of the Clover plots was, in March 1881, only 0.1058, which is considerably lower than was found in the same field many years before, and lower than has been found in any of the fields at Rothamsted excepting those where crops have been grown for many years on the same land without nitrogenous manure. It is a point of interest, however, that the percentage in the surface-soil is not so low as in immediately adjoining land, which has been under alternate Wheat and Fallow for nearly 30 years without manure.

The real interest of the results depends on the amounts, and on the difference in the amounts, of nitrogen, which the various plants have assimilated over a given area, all growing side by side on the same Red-clover-exhausted land, and with the same mineral manures, without any nitrogen supply.

Accordingly, the upper part of Table XV. (p. 32) shows the estimated average amounts of nitrogen in the Gramineous crop, Wheat, grown in alternation with Fallow, over 27 years to 1877 inclusive, and in the Red-clover, (together with other crops when it failed) over 29 years, also to 1877 inclusive. Then, in the body of the Table are given, the amounts of nitrogen in the Wheat alternated with Fallow, and in the produce of five different Leguminous plants, during the subsequent years, commencing with 1878, and ending with 1888.

Thus, over the preliminary period, the Wheat gave an average annual yield of nitrogen per acre of 17 lbs., and the Clover gave, over much the same period, an average of 32 lbs. of nitrogen.

Against these amounts, the various crops yielded, over the subsequent years, averages as follows:—The Fallow Wheat, over 11 years, 12 lbs.; the Red Clover (*Trifolium pratense*), over 8 years, 14 lbs.; the White Clover (*Trifolium repens*), over 11 years, 26 lbs.; the Vetch (*Vicia sativa*), over 11 years, 77 lbs.; the Bokhara Clover (*Melilotus leucantha*), 62 lbs.; and the Lucerne (*Medicago sativa*), over 11 years, 136 lbs.

Or, if we take the average amounts over the years of actual crop only, the amounts were—in the Wheat 22 lbs., in the Red Clover 22 lbs., in the White Clover 47 lbs., in the Vetch 77 lbs., in the Bokhara Clover 68 lbs., and in the Lucerne the enormous amount of 166 lbs., of nitrogen per acre per annum.

Again, if we take the total yields of nitrogen over the experimental periods, we have, in the Wheat 133 lbs., in the Red Clover 112 lbs., in the White Clover 283 lbs., in the Vetch 846 lbs., in the Bokhara Clover 679 lbs., and in the Lucerne 1,492 lbs.; that is, in the Lucerne

about eleven times as much as in the Wheat, and more than thirteen times as much as in the Red Clover. Indeed, this very deeply, and very powerfully rooting plant, yielded, in its above-ground produce alone, 337 lbs. of nitrogen in 1884, 270 lbs. in 1885, 167 lbs. in 1886, 247 lbs. in 1887, and 161 lbs. in 1888.

TABLE XV.

Estimated yield of Nitrogen per acre, in lbs., in Wheat alternated with Fallow, and in various Leguminous Crops, without Nitrogenous Manure.

	Un-manured Fallow Wheat.	Mineral Manures only.				
		Trifolium pratense.	Trifolium repens.	Vicia sativa.	Melilotus leucantha.	Medicago sativa.
PRELIMINARY PERIOD. WHEAT AND FALLOW, 27 yrs., 1851-'77. RED CLOVER, &c., 29 yrs., 1849-'77.						
Average per acre per annum ..	lbs. 17	lbs. 32				
EXPERIMENTAL PERIOD.						
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1878	29	0	0	51	53	0
1879	Fallow	50	82	46	130	0
1880	24	8	0	58	36	28
1881	Fallow	21	8	65	60	28
1882	18	18	74	146	145	111
1883	Fallow	0	0	101	27	143
1884	29	0	0	113	56	337
1885	Fallow	15	97	90	58	270
1886	14	Lupins	16	52	0	167
1887	Fallow	0	6	64	82	247
1888	19 {	Medicago sativa }	0	60	32	161
Total, 11 years, 1878-'88..	133	112*	283	846	679	1492
Average, 11 years, 1878-'88 ..	12	14*	26	77	62	136
Average for years of crop ...	22	22	47	77	68	166

* Eight years only, 1878-'85.

Not only have these large amounts of nitrogen been removed in the above-ground produce, but determinations of nitrogen in the surface-soils of the Vetch plot in 1883, and of the White Clover, the Bokhara Clover, and the Lucerne plots, in 1885, have shown, as in the case of the Clover after the Beans, that the surface-soil has gained rather than lost nitrogen, due to the accumulation of nitrogenous crop-residue. Here again, then, it is obvious, that the original source of the nitrogen of the crops has not been the surface-soil. It must have been derived either from the atmosphere or from the sub-soil.

The next results will throw some light on this point. Thus, having made initiative experiments of the same kind some years previously, in July, 1883, samples of soil were taken to the depth of 12 times 9 inches, or 108 inches in all, on the Wheat fallow plot, on the White Clover plot, and on two of the Vetch plots, for the determination of the

amount of nitrogen existing as nitric acid, at each depth. Table XVI. summarises the results.

TABLE XVI.

Nitrogen as Nitric Acid, per acre, lbs., in soils of some experimental plots, without Nitrogenous Manure for more than 30 years.

Hoosfield, Rothamsted.

Samples collected July 17-26, 1883.

Depths.	Wheat-Fallow Land. Unmanured.	Trifolium repens. Series 1. Plot 4.	Vicia sativa. Series 1. Plot 4.	Vicia sativa. Series 1. Plot 6.	Trifolium repens + or - Wheat Land.	+ or - Trifolium repens.	
						Vicia sativa. Plot 4.	Vicia sativa. Plot 6.
Inches.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1-9	19·85	30·90	12·16	10·22	+ 11·05	— 18·74	— 20·68
10-18	8·05	27·73	4·11	2·72	+ 19·68	— 23·62	— 25·01
19-27	2·47	8·44	1·37	1·08	+ 5·97	— 7·07	— 7·36
28-36	2·70	7·64	1·67	1·52	+ 4·94	— 5·97	— 6·12
37-45	1·62	9·07	4·58	2·51	+ 7·45	— 4·49	— 6·56
46-54	3·57	8·77	6·37	4·42	+ 5·20	— 2·40	— 4·35
55-63	3·84	7·92	7·16	4·52	+ 4·08	— 0·76	— 3·40
64-72	2·28	8·34	5·95	4·92	+ 6·06	— 2·39	— 3·42
73-81	1·48	8·27	4·54	4·81	+ 6·79	— 3·73	— 3·46
82-90	1·76	9·95	5·32	5·14	+ 8·19	— 4·63	— 4·81
91-99	2·94	9·16	5·66	6·40	+ 6·22	— 3·50	— 2·76
100-108	1·84	9·51	5·32	6·46	+ 7·67	— 4·19	— 3·05

SUMMARY.

1-27	30·37	67·07	17·64	14·02	+ 36·70	— 49·43	— 53·05
28-54	7·89	25·48	12·62	8·45	+ 17·59	— 12·86	— 17·03
55-81	7·60	24·53	17·65	14·25	+ 16·93	— 6·88	— 10·28
82-108	6·54	28·62	16·30	18·00	+ 22·08	— 12·32	— 10·62
1-54	38·26	92·55	30·26	22·47	+ 54·29	— 62·29	— 70·08
55-108	14·14	53·15	33·95	32·25	+ 39·01	— 19·20	— 20·90
1-108	52·40	145·70	64·21	54·72	+ 93·30	— 81·49	— 90·98

The first point to notice is that, at each depth, from the first to the twelfth, the *Trifolium repens* soil contains much more nitrogen as nitric acid than the Wheat fallow soil; and, as the figures at the bottom of the Table show, whilst to the total depth of 108 inches, or 9 feet, the Wheat fallow soil is estimated to contain per acre only 52·4 lbs. of nitrogen as nitric acid, the *Trifolium repens* soil, that is the Leguminous plant soil, contained to the same depth 145·7 lbs.

Now, independently of the fact that the Leguminous plant plots had received mineral manures, and the Wheat land had not, the characteristic difference in the history of the two plots was, that the one had, from time to time grown a Leguminous crop, and the other had not, and the one which had grown Leguminous crops contained, to the depth of 9 feet, nearly 3 times as much nitrogen as nitric acid as the Gramineous crop soil.

The difference is the greatest near the surface, but it is very considerable down to the lowest depths. In the first three depths,

there is more than twice as much nitrogen as nitric acid in the *Trifolium repens*, as in the Wheat fallow soil; in the second and third 3 depths, there is more than 3 times; and in the fourth 3, more than 4 times as much. Hence it is obvious, that any loss by drainage would be much the greater from the *Trifolium* plot, so that the difference between the two plots was probably greater than the figures show.

In the case of both plots the actual amount of nitrogen as nitric acid is the greatest near the surface, indicating more active nitrification; and the greater amount in the *Trifolium* soil is doubtless due to more nitrogenous crop-residue from the Leguminous than from the Gramineous crop. Indeed, as Table XV. (p. 32) shows, about 74 lbs. of nitrogen had been removed in the *Trifolium repens* crops, and only 18 lbs. in the Wheat, in 1882, and none from either in 1883, the year of soil sampling; and the crop-residue of the *Trifolium repens* would contain much more nitrogen than that of the Wheat. But it is not probable that the excess of nitric acid in the *Trifolium* soil, together with the larger amount lost by drainage, could be entirely due to the nitrification of recent crop-residue. Some found in the lower layers is, however, doubtless due to washing down from the surface. But as, notwithstanding much more nitrogen had been removed in the crops from the Leguminous than from the Gramineous crop land during the preceding 30 years, the surface-soil of the Leguminous plot remained slightly richer in nitrogen, it is obvious that the whole of the nitrogen of the nitric acid could not have had its origin in the surface-soil. If, therefore, it did not come from the atmosphere, it has been derived from the sub-soil.

The indication is, that nitrification is more active under the influence of Leguminous than of Gramineous growth and crop-residue. There would not only be more nitrogenous matter for nitrification, but it would seem that the development of the nitrifying organisms is the more favoured. Part of the result may, therefore, be due to the passage downwards of the organisms, and the nitrification of the organic nitrogen of the sub-soil.

An alternative is, that the soil and the sub-soil may still be the source of the nitrogen, but that the plants may take up, at any rate part, as ammonia, or as organic nitrogen. To this point I shall recur presently.

Comparing the amounts of nitrogen as nitric acid in the *Vicia sativa* soils, with those in the *Trifolium repens* soil, it is to be observed, that whilst from the *Trifolium repens* soil only 164 lbs. of nitrogen had been removed per acre in the crops of the five years to 1882 inclusive, 366 lbs. had been removed in the *Vicia* crops to the same date. Then, whilst none was removed in crops from the *Trifolium* plot in 1883, 101 lbs. were removed in the *Vicia* crops just before soil-sampling. Under these circumstances, one of the *Vicia* soils contains 81.5 lbs., and the other 91 lbs., less nitrogen as nitric acid per acre, than the *Trifolium repens* soil.

Of course we cannot know exactly how much was at the disposal of

the plants at the commencement of growth; but if there had only been as much as in the case of the *Trifolium* plot, it is seen that the deficiency in the *Vicia* soils nearly corresponds with the amount removed in the crop, which was 101 lbs. It may at any rate safely be concluded, that most, if not the whole, of the nitrogen of the *Vicia* crops, had been taken up as nitric acid.

But as the *Vicia* crops had removed much more in the preceding years than the *Trifolium* crops, so also would their crop-residue be greater; and, in fact, much more nitrogen must have been taken up by the plants each year than the figures show; and the larger the crop-residue, the larger would be the amount of nitric acid for each succeeding crop. But the crop of 1883 was also large, and it would leave a correspondingly large nitrogenous crop-residue; leaving, therefore, a large amount of the nitrogen assimilated to be otherwise accounted for than by previous crop-residue.

Lastly in reference to these experiments, it is seen that, at each of the 12 depths, the *Vicia* soils with growth, contained much less nitric acid than the *Trifolium* soil without growth; and the difference is much the greatest in the upper 4 or 5 depths, within which the *Vicia* throws out by far the larger proportion of its feeding roots; but the deficiency is quite distinct below this depth; the supposition being that, under the influence of the growth, water had been brought up from below, and with it nitric acid. In fact, the determinations showed that, down to the depth of 108 inches, the *Vicia* soils contained less water than the *Trifolium* soil, in amount corresponding to between 6 and 7 inches of rain, or to between 600 and 700 tons of water per acre.

Experiments of the same kind were again made in 1885. *Trifolium repens* was again selected as the weak and superficially rooting plant, *Melilotus leucantha* as a deeper and stronger rooting one, and the *Medicago sativa* as a still deeper, and still stronger rooting plant. Samples of soil were taken at the end of July and the beginning of August, from 2 places on each plot, and, in each case, as before, to 12 depths of 9 inches each, or to a total depth of 108 inches, or 9 feet. It will suffice to quote the results for the *Trifolium repens* and the *Medicago sativa* plots. They are given in Table XVII. (p. 36).

It is seen that there was much less nitrogen as nitric acid in the *Trifolium* soil in 1885, after the removal of 97 lbs. in the crops, than in 1883 (see Table XVI, p. 33), when there had been no crop. The deficiency is the greatest in the two upper layers, but it extends to the fifth depth, representing the range of the direct and indirect action of the superficial roots. Below this point there is, however, even more than in 1883; due, doubtless, in part to percolation from above during the two preceding seasons without growth, and possibly in part to percolation of the nitrifying organisms, and the nitrification of the nitrogen of the sub-soil.

Let us now compare the results relating to the *Medicago sativa* with those relating to the *Trifolium repens* soils.

TABLE XVII.

Nitrogen as Nitric Acid, per acre, lbs., in the soils and sub-soils of some experimental plots, without Nitrogenous Manure for more than 30 years.

Hoosfield, Rothamsted.

Samples collected July 29 to August 14, 1885.

Depths.	Series 1. Mineral Manures.		
	<i>Trifolium repens</i> . Plot 5.	<i>Medicago sativa</i> . Plot 5.	<i>Medicago sativa</i> + or - <i>Trifolium repens</i> .
Inches.	lbs.	lbs.	lbs.
1-9	11.60	8.88	— 2.62
10-18	1.38	1.11	— 0.27
19-27	0.90	0.78	— 0.12
28-36	1.86	0.81	— 1.05
37-45	7.08	0.99	— 6.09
46-54	11.31	0.93	— 10.38
55-63	13.14	0.67	— 12.57
64-72	12.63	0.81	— 11.82
73-81	11.19	0.70	— 10.49
82-90	10.70	0.61	— 10.09
91-99	11.08	0.44	— 10.64
100-108	9.96	0.41	— 9.55
Total ..	102.73	17.04	— 85.69
SUMMARY AND CONTROL.			
1-9	11.60	8.88	— 2.62
10-18	1.38	1.11	— 0.27
Mixture of 19-108 inches }	88.02	6.97	— 81.05
Total ..	100.90	16.96	— 83.94

The Table of the estimated nitrogen in the produce per acre (p. 32), shows that, whilst from the commencement to 1885 inclusive, the *Trifolium repens* yielded only 261 lbs. of nitrogen in crops, the *Medicago* gave 917 lbs.; and again, whilst in 1885, the year of soil-sampling, the *Trifolium* gave only 97 lbs., the *Medicago* gave 270 lbs. It is further to be observed that, quite accordantly with the usual character of growth of Lucerne in agriculture, with the increasing root-range, and consequently increased command of the stores of the soil and sub-soil, the yield of nitrogen increased from 28 lbs. in the first and second years, to 337 lbs. in the fifth year of growth, declining, however, somewhat afterwards.

Under these circumstances of very large yields of nitrogen in the crops, there is, at every one of the twelve depths, less, and at most very much less, nitrogen as nitric acid remaining in the soil than where so much less had been removed in the *Trifolium repens* crops. The difference is distinct even in the upper layers; but it is very striking in the lower depths. Thus, there is, on the average, not one-twelfth as much nitric-nitrogen in the lower 10 depths of the soil of the deep-rooting and high-nitrogen yielding *Medicago sativa*, as in those of

the shallow-rooting and comparatively low nitrogen yielding *Trifolium repens*. Indeed, the nitric acid is nearly exhausted in the deep-rooting *Medicago sativa* plot; there remaining, to the total depth of 9 feet, only about 17 lbs. of nitric-nitrogen, against more than 100 lbs. to the same depth in the *Trifolium repens* soil. The total deficiency of nitric-nitrogen in the *Medicago* as compared with the *Trifolium repens* soil, is seen to be 85.69 lbs. according to one set of determinations, and 83.94 lbs. according to the other.

As already said, we cannot know what was the stock of nitric-nitrogen in the soil at the commencement of the growth of the season, or the amount formed during the growing period. But, with so much more *Medicago* growth for several previous years, it seems reasonable to assume that there would be much more nitrogenous crop-residue for nitrification than in the case of the *Trifolium repens* plot.

But even supposing, for the sake of illustration, that each year's growth would leave crop-residue yielding an amount of nitrogen as nitric acid for the next crop, or succeeding crops, approximately equal to the amount which had been removed in the crop, the increasing amounts of nitrogen yielded in the crops from year to year could not be so accounted for; and there would remain the amount of nitrogen in the crop-residue itself, still to be provided in addition. In fact, assuming the proportion of nitrogen in the crop-residue to that in the removed crop to be as supposed in the above illustration, nearly 700 lbs. of nitrogen would have been required for the *Medicago* crop and crop-residue of 1884; or, if we assume the nitrogen in the residue to be only half that in the crop, about 500 lbs. would have been required. Doubtless, however, some of the nitrogenous crop-residue would accumulate from year to year.

The results can leave no doubt that the *Trifolium repens*, and the *Medicago sativa*, have each taken up much nitrogen from nitric acid within the soil, and that, in fact, nitric acid is an important source of the nitrogen of the Leguminosæ. Indeed, existing direct experimental evidence relating to nitric acid, carries us quantitatively further than any other line of explanation. But, it is obviously quite inadequate to account for the facts of growth, either in the case of the *Medicago sativa* after the Clover, or in that of the Clover after the Beans.

It is obvious that, if nitric acid were the source of the whole, there must have been a great deal formed by the nitrification of the nitrogen of the sub-soil. A difficulty in the way of the assumption that nitric acid is the exclusive, or even the main source of the nitrogen of the Leguminosæ is, that the direct application of nitrates as manure, has comparatively little effect on the growth of such plants. In the case of the direct application of nitrates, however, the nitric acid will percolate chiefly as sodium or calcium nitrate, unaccompanied by the other necessary mineral constituents in an available form; whereas, in the case of nitric acid being formed by direct action on the sub-soil, it is probable that it will be associated with other constituents, liberated, and so rendered available, at the same time.

EXPERIMENTS ON THE NITRIFICATION OF SOILS AND SUB-SOILS.

It was obviously important to determine by direct experiment, whether the nitrogen existing in a comparatively insoluble condition in raw clay sub-soil, was susceptible of nitrification.

It had already been found at Rothamsted, that the sub-soils of rich *Prairie-land* were subject to nitrification; but considering the conditions of the collection and transmission of the samples in question, it was considered possible that comparatively recent organic matter from the surface-soil might not have been entirely excluded. Accordingly, experiments were made with some of the Rothamsted raw clay sub-soils.

The percentages of total nitrogen in the samples was determined. The nitrogen as nitric acid was determined in the dry sifted soil, both before and after exposure for some months under suitable conditions as to temperature and moisture. After the first extraction, the soils were seeded with from 0.1 to 0.2 gram of rich garden-soil, assumed to contain nitrifying organisms, and by 0.2 gram more after some subsequent extractions. Further, after 3 or 4 extractions, which had of course removed the soluble mineral matters, a mineral mixture was added.

The results have been given and discussed in detail elsewhere, and their general indication may be stated as follows:—Results obtained with raw, and mostly clay, sub-soils, which contain not more than 6 or 8 parts of carbon to 1 of nitrogen, confirm those previously obtained with *Prairie* sub-soils containing a much higher proportion of carbon, in showing that their nitrogen is susceptible of nitrification, provided the organisms, and other essential conditions, are not wanting. The results also consistently showed, that there is more active nitrification in *Leguminous* than in *Gramineous* crop sub-soils. This, it must be supposed, is partly due to more active development, and greater distribution, of the organisms themselves, under the influence of the *Leguminous* growth, with its excretions and residue, and partly to the greater actual amount of such easily changeable matters, with the greater amount of nitrogenous crop-residue.

The results are also confirmed by those of experiments made in the Rothamsted Laboratory by Mr. Warrington, on quite distinct lines. His plan was to introduce a portion of the sub-soil into a sterilized nitrogenous liquid, and to determine whether nitrification took place; the result being taken to show whether or not the organisms were present in the sub-soil. From his first results he concluded that in our clay soils the nitrifying organism is not uniformly distributed much below 9 inches from the surface; that it is sparsely distributed down to 18 inches, or possibly somewhat further; but that at depths from 2 feet to 8 feet, there was no trustworthy evidence to show that the clay contained the nitrifying organism.

Subsequently, he experimented with a greater variety of sub-soils, and with some taken in the immediate neighbourhood of lucerne roots, and gypsum was added to the sterilized liquids.

Among the 69 experiments made in this new series, there was no failure to produce nitrification by samples down to 2 feet; there was only one failure out of 11 trials down to 3 feet; but below 3 feet, the failures were more numerous. Taken at 6 feet, about half the samples induced nitrification. The order of priority of nitrification diminished from the upper to the lower depths; indicating more sparse occurrence, or more feeble power of development and action. There was, moreover, notably more active nitrification with the Leguminous than with the Gramineous crop sub-soils.

It is, then, established, that the nitrogenous matters of raw clay sub-soils are susceptible of nitrification, if the organisms, with the other necessary conditions, are present. It is further indicated, not only that the action is more marked under the influence of Leguminous than of Gramineous growth and crop-residue, but that the organisms become distributed to a considerable depth, even in raw clay sub-soils, especially where deep rooted and free growing Leguminosæ have developed.

The next question is, how far, in a quantitative sense, do the results aid us in explaining the source of the large amounts of nitrogen taken up by some Leguminous crops?

In the case of three Leguminous crop sub-soils there was, over the total period, only about 1 part of nitrogen nitrified per million of soil; and as the sub-soil, to the depth experimented on, would weigh about 30 million lbs. per acre, the amount of nitrification supposed would represent only about 30 lbs. of nitric-nitrogen per acre. Obviously the conditions of nitrification in which the samples are exposed in the Laboratory are very different from those of the sub-soil *in situ*. Thus, whilst in the case of the samples in the Laboratory, the conditions as to temperature, and, perhaps of aëration, would be the more favourable, the successive extractions by water under pressure, would be liable to remove, not only the mineral matters essential for the development of the organisms, and for the production of nitric acid, but the organisms themselves; whereas, in the case of the natural sub-soil, the tendency would be to multiplication.

Compared with the small amount of nitrification of the nitrogen of the raw clay sub-soils shown in the foregoing experiments, some results obtained by Mr. Warrington, in experiments in which he mixed raw clay sub-soil with an equal weight of coarsely powdered flint, seeded the mixture with rich garden-soil, moistened it, and placed it in a vessel allowing of free access of washed air, show, in one case 12.9 and in the other 11.8 parts of nitrogen nitrified per million of sub-soil; and, when mineral plant food was added to the subsoils, the amounts of nitrogen nitrified were raised to 21.4, and 14.2, parts, per million. It is obvious, therefore, that there would be little difficulty in accounting even for the large amounts of nitrogen taken up by the *Medicago sativa* were it established, which it certainly is not, that coincidentally with the deep-rooted growth, both the nitrifying organisms, and air, were abundantly present in the sub-soil.

Indeed, the greatest difficulty in the way of the supposition that much nitrogen is available to plants by the nitrification of the nitrogen of the sub-soil, is the want of sufficient aëration. Independently of the greater or less porosity of the sub-soil itself, and of the channels formed by worms, it is obvious that, wherever the roots go, water and its contents can follow; and that, with deep-rooted plants, and free growth, there will be active movement of water, and there must be of air also, in the lower layers of the soil. In experiments made in 1882, there remained in the *Melilotus* soil, less water than in the *Trifolium repens* soil where there had been less growth, in amount corresponding, down to a depth of 54 inches, to a loss of 540 tons per acre, or nearly $5\frac{1}{2}$ inches of rain; and, as already stated, in 1883, the *Vicia sativa* soils showed, down to 108 inches, less water than the *Trifolium repens* soil, in amount corresponding to between 600 and 700 tons per acre, or to between 6 and 7 inches of rain. Obviously too, the still deeper rooting, and still freer growing, *Medicago sativa*, would remove still more water.

Although much experiment, and much calculation, have been devoted by several investigators to the estimation of the degree of aëration of soils and sub-soils of different character, the data at command do not justify any very definite conclusions on the subject. The results seem to indicate a probable range of aëration from about 30 to over 50 per cent. of the volume of the soil. But these estimates do not take into account the varying amounts of water in the soil or sub-soil. In the case of the sub-soils above referred to, each layer of 9 inches in depth retained from about 2 to nearly 4 inches of water, the amount varying very much, according to the nature of the sub-soil, and especially according to the amount of growth, and the consequent withdrawal of water from below, and its evaporation, chiefly through the plant, but partly also from the surface soil. The amount must, obviously, also vary very much according to the character of the season.

It may be stated that, supposing the sub-soil contained at one time, air equal to one third of its volume, this would not suffice for the nitrification of as much nitrogen as was taken up each year, for several years in succession, by the *Medicago sativa*; or during the two years in the case of the Red-clover on the Bean-exhausted land. But the nitrogen is not taken up all at once, though much of it will be within a few months of the year, during which period there would be the most active withdrawal of water from below, and evolution by the plant, and evaporation by the surface-soil. The replacement of this sub-soil water by an equal volume of air would, however, still not suffice. The question obviously arises—how far, or how rapidly, the used up oxygen will be replaced, and on this point there is very little experimental evidence to aid us.

Thus, then, the evidence is clear, that the nitrogen of raw clay sub-soils, which constitutes an enormous store of already combined nitrogen, is susceptible of nitrification, provided the organisms are

present, and the supply of oxygen is sufficient; but the data at command do not justify the conclusion that these conditions would be adequately available in such cases as those of the very large accumulations of nitrogen by the Red-clover grown after the Beans, and of the increasing, and very large accumulations, by the *Medicago sativa*, for a number of years in succession.

The alternatives are—either that the plant may take up nitrogen from the sub-soil in some other way, as ammonia, or as organic nitrogen; or that the free nitrogen of the atmosphere is in some way brought under contribution.

CAN ROOTS, BY VIRTUE OF THEIR ACID SAP, ATTACK, AND RENDER AVAILABLE, THE OTHERWISE INSOLUBLE NITROGEN OF THE SUB-SOIL?

In reference to the first of the above alternatives, the question suggested itself whether roots, by virtue of their acid sap, may not, either directly take up, or at any rate attack and liberate for further change, the otherwise insoluble organic nitrogen of the sub-soil?

Accordingly, in the autumn of 1885, specimens of the deep, strong, fleshy root of the *Medicago sativa* were collected and examined; when it was found that the sap was very strongly acid. The degree of acidity of the juice was determined; and attempts were made so to free the extract from nitrogenous bodies as to render it available for determining whether or not it would attack and take up the nitrogen of the raw clay sub-soil. Hitherto, however, these attempts have been unsuccessful. But it may be of interest to state, as indicating the extent of the command of the sub-soil which such plants acquire, that, of the 3 plants collected, the roots of one had four branches, respectively, 6 feet 4½ inches, 5 feet 10½ inches, 3 feet 6½ inches, and 2 feet 9½ inches, in length; the second had two branches—4 feet 10, and 2 feet 2 inches, long; and the third two branches—3 feet 9, and 1 foot 9 inches, in length.

ACTION OF DILUTE ORGANIC ACID SOLUTIONS ON THE NITROGEN OF SOILS AND SUB-SOILS.

Experiments were next made to determine the action on soils and sub-soils, of various organic acids, in solutions of a degree of acidity either approximately the same as that of the *Medicago sativa* root-juice, or having a known relation to it. These experiments and their results have been fully detailed elsewhere, and only their general indications can be referred to here.

Obviously, however, the conditions of experiments in which an acid solution is agitated with a quantity of soil in a bottle, are not comparable with those of the action of living roots on the soil. The root action would necessarily affect only a very small proportion of the total soil. But the results showed, that the more nitrogen was taken up the greater the acidity of the solution, and the question arises,

whether the root action would not effect more resolution on the surfaces actually attacked. Indeed, this must necessarily be the case, if such an action is really quantitatively an important source of the nitrogen taken up by deep and strong rooting plants, with strongly acid-sap. In illustration of this necessity it may be stated that, even if as much as 20 parts of nitrogen were taken up per million of soil, as was the case in some of the experiments, this would only represent 600 lbs. of nitrogen per acre to the depth examined, namely, 108 inches.

Upon the whole, the experiments on the action of weak organic acid solutions on raw clay sub-soil, did not give results from which any very definite conclusions can be drawn, as to the probability that the action of roots on the soil, by virtue of their acid sap, is quantitatively an important source of the nitrogen of plants having an extended development of roots, of which the sap is strongly acid.

That roots do attack certain mineral substances by virtue of their acid-sap, was established by Sachs. It was to carbonic acid that he attributed the action ; but there seems no reason to suppose that other acids in the root-sap may not exert a similar action. The published results of Sachs and others have, however, reference only to the taking up of mineral substances from the soil by virtue of such an action ; and the possibility or probability that the nitrogen of the soil or sub-soil is so taken up, has, I believe, not been considered.

As bearing on the point, it may be stated that Dr. G. Loges and M.M. Berthelot and André, by extracting rich soils by strong hydrochloric acid, have found that soluble amides are obtained. Supposing the acid root-sap so to act on the insoluble organic nitrogen of the soil, and especially of the sub-soil, the question would still remain—whether the amide rendered soluble is taken up by the plant as such, as seems to be probable in the case of the fungi, or whether it undergoes further change—into ammonia or nitric acid—before serving as food for the plants ?

The first point to consider is, then, whether chlorophyllous plants can take up amide-bodies and assimilate their nitrogen ?

Many vegetation experiments have been made to determine this point. In the case of experiments in which soil was used as a matrix, it seemed probable that the amide-body suffered change before becoming available as a source of nitrogen. In the case of some water-culture experiments, however, it was concluded that the amide-body was taken up by the plant as such, and contributed directly as a source of nitrogen to it. It would seem not improbable, therefore, that they might take up directly, and utilize, amide-bodies rendered soluble within the soil by the action of their acid root-sap.

As a portion of the nitrogen of the soil, when acted upon by acids, is liberated as ammonia, it is a question whether this will be either wholly, or partially, nitrified, before being taken up by the plant. Obviously, too, if the portion brought into the condition of soluble amide, be not taken up as such, it also will be subject to further change ; perhaps first into ammonia, and then into nitric acid. But, on such a supposition,

we should obviously be again met with the difficulties in the way of assuming that the conditions within the sub-soil would be adequate for so much nitrification.

It will be seen, therefore, that although significant indications have been obtained, both as to the importance of nitric acid as a source of the nitrogen of the Leguminosæ, and as to the action of acids in rendering soluble the otherwise insoluble nitrogenous compounds of soils and sub-soils, yet on neither of these points is the evidence at present available, adequate to account satisfactorily for the facts of growth.

It will be of interest, briefly to refer to some evidence relating to another mode in which green-leaved plants may acquire nitrogen from the stores already existing in the combined state, but in an insoluble condition, in the soil and sub-soil.

Thus, Professor Frank has observed that the feeding roots of certain trees are covered with a fungus, the threads of which force themselves between the epidermal cells into the root itself, investing the cell, but not penetrating the fibro-vascular tissue. In such cases the root itself has no hairs; but there are similar bodies external to the fungus-mantle, which are prolonged into threads among the particles of soil. The fungus-mantle dies off on the older portions of the root, and its extension is confined to the younger parts, those which are active in the acquirement of nutriment.

Frank considers that the conditions are those of true symbiosis; and that the chlorophyllous tree acquires the carbon, and the fungus the water and the mineral matters, that is the soil-nutrient. He did not refer to nitrogen, but there seems no reason to suppose that the fungus could not, as do the fungi in the case of fairy rings for example, avail itself of the organic nitrogen of the soil.

Here, then, is a mode of accumulation of soil-nutrient by some green leaved plants, which so far allies them very closely to fungi themselves. Indeed, it is by an action on the soil which characterises *non-chlorophyllous* plants, and by virtue of which they are enabled to take up nutriment not available to most green-leaved plants, that the chlorophyllous plant itself acquires its soil supplies of nutriment. It can readily be supposed that, under such circumstances, the tree may acquire not only water and mineral matter, but both organic carbon, and organic nitrogen, from the soil. In reference to this point it may be stated that, from the evidence so far at command, it was concluded that the action is the most marked in the surface layers of the soil rich in humus.

So far as this is the case, it is obvious that such an action of fungi on the soil does not aid us in the explanation of the acquirement of nitrogen from raw clay sub-soil, by the deep and strong rooted Leguminosæ.

Further, it is distinctly stated, that the fungus development in question has not been observed on the roots of any herbaceous plants. It is, nevertheless, a point of interest, should it be established, that by

special means, in special cases, the organic nitrogen of the soil may contribute to the supply of nitrogen to chlorophyllous plants.

I have now considered in some detail the sources of already combined nitrogen available to our crops; and the evidence points to the conclusion that, independently of the small amount of combined nitrogen annually coming from the atmosphere in rain, and the minor aqueous deposits, the source of the nitrogen, at any rate of most of our crops, is the stores already existing within the soil and sub-soil, or those provided by manure. It has further been seen that the combined nitrogen is largely taken up as nitric acid, or rather as nitrates. But it is nevertheless obvious, that we have yet to seek for an explanation of the source of the whole of the nitrogen of the Leguminosæ in some cases.

We are brought to enquire, therefore, what is the evidence relating to the question of *the fixation of free nitrogen*, by the plant, by the soil, or otherwise?

EVIDENCE AS TO THE FIXATION OF FREE NITROGEN.

Even nearly a century ago, it was a matter of discussion whether plants took up, or evolved, free nitrogen; and it is just about half a century, since Boussingault commenced a series of vegetation experiments to determine whether plants do assimilate the free nitrogen of the atmosphere. From the results then and subsequently obtained, he concluded that they did not; and results obtained at Rothamsted nearly 30 years ago confirmed those of Boussingault. But others came to an opposite conclusion; and a somewhat active controversy was maintained on the subject for some time. Eventually it seemed to be pretty generally admitted, that plants did not directly assimilate the free nitrogen of the air. During the last few years, however, the discussion has assumed a somewhat different aspect.

The question still is, whether the free nitrogen of the air is an important source of the nitrogen of vegetation; but whilst few now adhere to the view that chlorophyllous plants directly assimilate free nitrogen; it is nevertheless assumed to be brought under contribution in various ways—coming into combination within the soil, under the influence of electricity, or of micro-organisms, or of other low forms, and so indirectly serving as an important source of the nitrogen of plants of a higher order.

Several of the investigations in the lines here indicated, seem to have been instigated by the assumption, that natural compensation must be found, for the losses of combined nitrogen which the soil sustains by the removal of crops; and for the losses which result from the liberation of nitrogen from its combinations, under various circumstances.

It was about 1876, that M. Berthelot called in question the legitimacy of the conclusion that plants do not assimilate the free

nitrogen of the air, when drawn from the results of experiments in which the plants were so enclosed as to exclude the possibility of electrical action. More recently, he has objected to experiments so conducted with sterilised materials, on the ground that, under such conditions, the presence, development, and action, of micro-organisms, are excluded.

There is, however, I believe, nothing in the recent results, either of Berthelot or of others, which can be held to invalidate the conclusion, drawn from the results of Boussingault, and from those obtained at Rothamsted about 30 years ago, that the higher plants do not fix the free nitrogen of the atmosphere, under the conditions then adopted, which, it is admitted, were such as to exclude, both electrical action, and the influence of micro-organisms.

I propose now to give a brief account of recently published results and conclusions from experiments for the most part made under such conditions as not to exclude the possibility of the influence of electricity, or of micro-organisms. The first to notice are those of M. Berthelot himself.

M. Berthelot first showed that free nitrogen was fixed by various organic compounds, under the influence of the silent electric discharge, at the ordinary temperature; and he suggested that such actions probably take place in the air during storms, and when the atmosphere is charged with electricity, organic matters absorbing nitrogen and oxygen. He also experimented with currents of much weaker tension, more comparable with those incessantly occurring in the air, and in all cases he found that nitrogen was fixed by the organic substance. The gains were in amount such as would explain the source of the nitrogen which he considers crops must derive from the atmosphere.

Subsequently, he found that free nitrogen was brought into combination by argillaceous soils, when exposed in their natural condition, but not when they were sterilised. He also found gain when the natural soils were enclosed. He considered the results showed that there was gain of nitrogen quite independently of any absorption of combined nitrogen; in fact that there was fixation of free nitrogen due to living organisms. He further considered that such gains, not only serve as compensation for exhaustion by cropping, &c., but explain how originally sterile argillaceous soils eventually become vegetable moulds.

He also made experiments on the fixation of free nitrogen by vegetable earth supporting vegetation; and he found that there was a gain about equally divided between the soil and the plant, the latter having taken it up from the soil, which he considers is the true source of gain.

The results obtained under the influence of the silent discharge in bringing free nitrogen into combination with certain vegetable principles, of course owed their special interest to the inference that thus free nitrogen might be brought into combination within the soil, or within the plant; but M. Berthelot subsequently considered it doubtful

whether the higher plants do bring free nitrogen into combination at all. Quite recently, however, he has made new experiments, from which he concludes that nitrogen is fixed under the influence of electricity, both in the soil with its microbes, but without higher vegetation, and in soil with higher vegetation.

Obviously if there are organic compounds within the soil which have the power of bringing free nitrogen into combination under the influence of electricity, the soil may be the source, and yet the agent may be the feeble electric current. But, so far as it is assumed that free nitrogen is brought into combination in the atmosphere itself, the resulting compounds will be found in the air, and in the aqueous depositions from it; and the limit of the amount of combined nitrogen so available over a given area, in Europe at any rate, is pretty well known.

M. Dehérain sought to determine the actual losses or gains in the field, under the influence of different manures, of different crops, and of different modes of cultivation. Experiments were made with various crops, each of which was grown without manure, and with three different descriptions of manure, applied for a series of years, and then the crop was grown without manure for some years more.

The nitrogen was determined in the soil, before the commencement of the experiments in 1875; in 1878 after three years of manuring and cropping; in 1881 after four years' cropping without further manuring; and in the case of sainfoin followed by mixed grasses, in 1885 also. Lastly, the nitrogen in the crops was only estimated. From these data, the losses or gains of nitrogen by the soil, during the different periods, under the influence of the different manures and crops, were calculated.

With regard to the actual amounts of loss or gain of nitrogen found in M. Dehérain's experiments, the losses especially are extremely large, indeed they were far in excess of anything that has come within our own knowledge and experience, and they were in amount such as reflection must show cannot possibly occur in actual practice.

The question arises—how are such results to be explained? I think there can be little doubt that in the method of taking the samples of soil for analysis, an explanation is to be found; and I have the less hesitation in suggesting this, since we fully admit, that our own early results, obtained under somewhat similar conditions, are quite inapplicable for anything like accurate estimates of nitrogen per acre.

In fact, it may be concluded that, certainly the estimated losses by the surface-soils, and probably also the estimated gains, are higher than can possibly happen in practice; and that the results are due to the samples of soil not being taken in such a way, as to ensure strictly comparable estimates at the different periods. At the same time, there can be no doubt that there would be losses beyond those due to the removal of the crops, under the conditions in which losses were found; that is when the land was under arable culture. Nor can there be any doubt that there would be gains in the surface-soil, when the land was

laid down in sainfoin and mixed grasses; and M. Dehérain points out the practical significance of such facts.

M. Dehérain concluded that the loss of nitrogen by arable soil, that is by soil that is mechanically worked, is due to the slow combustion of the nitrogenous organic matter of the soil; the nitrogen being either evolved as free nitrogen, or oxidated into nitric acid and carried down into the sub-soil, or into the drains. As to the gain by the surface-soil, he considers, as is doubtless the case, that part is due to the action of deep-rooted plants, in taking up the nitric acid accumulated in the lower layers, and leaving a nitrogenous residue near the surface; and that as to the gains not so to be accounted for, it is not yet settled whether they are due to the ammonia of the atmosphere, as supposed by M. Schloësing, or to free nitrogen, as supposed by M. Berthelot.

It may be remarked, that, if the losses in ordinary agriculture were in amount anything like those which M. Dehérain's figures show, even such large gains as are also indicated, would be far from sufficient to compensate them. It would indeed be necessary to seek for other sources of restoration, if our arable surface-soils are not to lose their nitrogen much faster than the evidence at command leads us to suppose is the case in actual practice. That they do, however, slowly suffer reduction in their stock of nitrogen, when there is no restoration from without, there can be no doubt. In other words, in actual practice without restoration from external sources, the losses are not fully compensated.

In conclusion in regard to M. Dehérain's experiments, I may add that he has quite recently reiterated his results and conclusions; but he does not say anything that appears to us to obviate our objections to his quantitative estimates.

M. Joulie made numerous vegetation experiments in which the soils and the plants were, with certain precautions, exposed to the free air, and in which known amounts of combined nitrogen were supplied. He found very variable, but in some cases very large, gains of nitrogen. He considered that the variations of result were largely due to the varying conditions as to mineral-supply in the different experiments.

M. Joulie concluded that microbes probably play an important part in the fixation of nitrogen. He did not think that his results were favourable to the supposition that the plants themselves effected the fixation. For the present he limits himself to the establishment of the great fact of the fixation of the free nitrogen of the atmosphere, leaving to the future the exact explanation.

It is to be observed that the large gains shown were chiefly with a polygonous plant, Buckwheat, and not with plants of the Leguminous family, which are reputed to be "nitrogen collectors."

To show the practical importance of the fixation of free nitrogen, M. Joulie calculates what would be the gain per hectare according to some of his results. It may be confidently affirmed, however, that such gains as he so estimates, do not take place, either with or without vegetation, in ordinary soils, in ordinary practice.

Dr. B. E. Dietzell made vegetation experiments, in which plants were watered with distilled water, the drainage was returned to the soils, and the pots and their contents were exposed to free air, but protected by a linen roof. A rich garden soil, containing 0.415 per cent. of nitrogen, was used, several different conditions as to manuring were adopted, and Peas and Clover were the subjects of experiment. Thus, the plants were of the Leguminous family; but notwithstanding this, there was, in no case, a gain of nitrogen. In one there was neither gain nor loss, and in all the others there was a loss, in some cases amounting to 15 per cent. of the total nitrogen involved.

That there should be loss with a soil containing 0.415 per cent. of nitrogen, that is about three times as much as most ordinary arable soils, is not at all surprising; and it is seen that, neither from the combined nitrogen of the atmosphere, or that due to other accidental sources, nor from free nitrogen, either directly or indirectly, did these reputed "nitrogen collectors" gain nitrogen to compensate the losses from the rich soil.

Professor Frank also made vegetation experiments in free air. His soil was a humus-sand, containing only 0.0957 per cent. of nitrogen; distilled water was used for watering, and the vessels were deep and narrow cylinders, without any arrangement at the bottom for drainage, or for aëration. In three experiments without a plant, in one with two Lupins, and in one with one Lupin and Incarnate Clover together, there was a loss of nitrogen; whilst in one with three Lupins, and in one with one Lupin, there was a gain. Frank considered it probable that where a loss was indicated with vegetation, there had nevertheless been a gain, but not enough to compensate the loss.

In another experiment, with a soil about 12 times as rich in nitrogen, and many times richer than ordinary arable soils, he found a loss, due mainly to evolution of free nitrogen; and, referring to this result, he says that, if such losses take place in ordinary agriculture, there must be natural compensation.

In the experiments in the deep and narrow vessels, without drainage, and without plants to cause evaporation, movement, and aëration, loss by evolution of free nitrogen is only what would be expected. Such loss would also be expected in the two cases of loss with growth, in both of which there was admittedly decomposing organic matter. It was also to be expected in the very rich soil. But it is doubtful whether, in the two cases of gain with growth, and therefore movement within the soil, and aëration of it, there would be any loss. In none of the experiments with loss, however, were the conditions comparable with those of ordinary soils, under ordinary treatment; and the losses found cannot be taken as any indication of what takes place in ordinary practice. It is probable that, in such practice, the loss by evolution of free nitrogen is much less than is generally assumed in discussions of this subject. Doubtless there is, however, frequently considerable loss by the drainage of nitrates.

Frank considers that, independently of direct evidence against the

supposition that the gains were due to the absorption of combined nitrogen from the atmosphere, an objection to such a view is, that it would not explain the circulation of nitrogen in nature; and his main conclusion is, that there are two actions going on within the soil, one liberating nitrogen, and the other bringing it into combination, the latter favoured by vegetation.

Upon the whole, then, it would seem, that the losses found by Frank may be explained by the special conditions of the experiments themselves; whilst the gains, if not to be accounted for by sources of error incidental to experiments made in free air, can only be explained by fixation in some way.

The most remarkable of the results indicating the fixation of free nitrogen are those of Professor Hellriegel and Dr. Wilfarth. Hellriegel found that whilst plants of the Gramineous, the Chenopodiaceous, the Polygonous, and the Cruciferous families, required combined nitrogen to be supplied within the soil, Papilionaceous plants did not depend on such soil-supplies.

Peas, sown in washed sand with nutritive solutions free from nitrogen, generally failed, but occasionally grew luxuriantly; and root-nodules were always developed coincidently with luxuriance, but not without it. But when to the non-nitrogenous sandy matrix, a few c.c. of the watery extract of a rich soil were added, the luxuriance was always marked, as also was the development of the root-nodules. Lupins, however, failed when treated in the same way, but succeeded when the soil was seeded by a watery extract of a sandy soil where Lupins were growing well, and root-nodules were then abundantly produced.

The amounts of produce recorded seemed to leave no doubt that they contained much more nitrogen than was supplied in the seed; whilst the amount added in the soil-extract was quite immaterial. The negative result with Gramineæ, with Peas under sterilised conditions, or in sand not seeded with rich soil-extract, and with Lupins in sand not seeded, or seeded with the rich soil-extract, and, on the other hand, the positive result with Peas in the seeded sand, and with Lupins when the sand was seeded with an extract from a suitable soil, seemed to exclude the supposition of any other source of gain than the fixation of free nitrogen under the influence of micro-organisms; and Hellriegel was disposed to connect the action with the root-nodules and their contents.

Wilfarth gave the results of a subsequent season's experiments, which fully confirmed those recorded by Hellriegel, both as to the negative result with other plants, and to the positive result with Papilionaceæ. Peas grew luxuriantly when the nitrogen-free soil was seeded with the watery extract from any cultivated soil, but *Serradella* and Lupins, only when seeded with an extract from soil where these plants were growing.

In four experiments with Lupins, nearly 50 times as much dry substance was produced, and nearly 100 times as much nitrogen was assimilated, with, as without, seeding with the soil-extract!

Wilfarth concluded that the Papilionaceæ can derive the whole of their nitrogen from the air, but that it is doubtful whether the root-nodules are connected with the fixation, though the results point to the agency of bacteria in some way.

In reference to these results, whilst it can hardly be said that there is an unsolved problem in regard to the source of the nitrogen of our *non*-Leguminous crops, it must be admitted that, in spite of all the investigations and discussions of the last 50 years, the source of the whole of the nitrogen of our Leguminous crops has not been satisfactorily explained by results obtained on the lines of inquiry until recently adopted. Evidence obtained on new lines should, therefore, receive careful consideration; and there can be no doubt that, in recent years, cumulative evidence has been adduced, indicating that Chlorophyllous plants may avail themselves of nitrogen brought into combination under the influence of lower organisms; the development and action of which would seem in some cases to be a coincident of the growth of the higher plants to be benefited. But such a conclusion is of such fundamental importance, that it seemed desirable it should be confirmed by others. To some results obtained at Rothamsted in this direction, I shall refer further on.

So long ago as 1853, Professor Emil von Wolff obtained 6 times as much dry produce of Clover, grown in an ignited rich meadow soil, as in the same soil in its natural state. Thus, the increased growth, and the increased assimilation of nitrogen, took place in a soil not only nitrogen-free, but sterilised; so that, unless micro-organisms were acquired during growth, the supposition of their influence in fixing free nitrogen would be excluded.

Much more recently, Wolff has made numerous experiments, with Oats, Potatoes, and various Papilionaceæ, in river-sand; in some cases unwashed, and in some washed; in some without manure, in some with purely mineral manure, and in some with nitrate in addition. Accordantly with common experience, there was little increase in the Oats or Potatoes with mineral, but much with nitrogenous manure; and, on the other hand, with the Papilionaceæ there was very marked increase with the mineral manure, and but little more by adding nitrate. In the experiments with Lupins, Beans, and Clover, in unwashed sand, the results indicated gain of nitrogen, beyond that probably due to the nitrogenous impurity in the sand; but with sand-Peas, grown in washed sand, which was assumed to be nitrogen-free, the gains from some external source were unmistakable.

As to the explanation, Wolff does not suppose that free nitrogen is fixed by the plants themselves; nor does he favour the view that it was fixed by the agency of micro-organisms. The plants may take up combined nitrogen from the air by their leaves; but he thinks it more probable that combined nitrogen is absorbed from the air by the soil, and that free nitrogen is fixed within the soil under the influence of porous and alkaline bodies. He admits that it is not explained why Cereals do not benefit by these actions as well as Papilionaceæ; and he

suggests whether the greater evaporation from the leaves of the latter causes greater aëration of the soil.

Here, then, the gain of nitrogen by the Leguminosæ is explained in a very different manner from that assumed by other recent experimenters. It seems, however, that the undoubted fact, that the Gramineæ, and other non-Papilionaceous crops, do not benefit by the actions supposed, excludes the supposition that Wolff's results with Papilionaceæ are to be so explained. It is true that, neither in the growth of the Clover in ignited soil, nor in that of the sand-Peas in the washed sand, were the conditions such as would seem favourable for the presence, development, and agency of micro-organisms. But if, in the experiments in free air, there was no accidental source of combined nitrogen, it would seem that the influence of micro-organisms is at least as probable as that of the actions which Wolff supposes.

Professor Atwater made numerous experiments, both on the germination, and on the growth, of Peas. In eleven out of thirteen experiments on germination, more or less loss of nitrogen was observed. In all but one out of fifteen experiments on vegetation, there was a gain of nitrogen, which was very variable in amount, and sometimes very large. As a general conclusion, he states that, in some of the experiments half or more of the total nitrogen of the plants was acquired from the air.

He considers that germination without loss of nitrogen is the normal process; that loss, whether during germination or growth, is due to decay, and therefore only accessory. Nevertheless, he goes into calculations of some of his own results, showing, by the side of the actual gains, the greater gains supposing there had been a loss of 15 per cent. of nitrogen, and the still greater gains if there had been a loss of 45 per cent., as in an experiment by Boussingault under special conditions. Further, he says that whilst actually observed gains are proof of the acquisition of nitrogen, the failure to show gain only proves non-fixation, if it be proved that there was no liberation. He suggests that the negative results obtained by Boussingault and at Rothamsted, may be accounted for by liberation; though at the same time he recognises that the conditions of the experiments excluded the action of either electricity or microbes. It may be remarked that, in the experiments both of Boussingault and at Rothamsted, any cases of decay were carefully observed, and the losses found explained accordingly; and it may be confidently asserted that the conclusions drawn were not vitiated by any such loss.

Atwater concludes that his results do not settle whether the nitrogen gained was acquired as free or combined nitrogen, by the foliage, or by the soil. He considers, however, that, in his experiments, the conditions were not favourable for the action either of electricity or of micro-organisms; and he favours the assumption that the plants themselves were the agents. Lastly, he considers the fact of the acquisition of free nitrogen in some way to be well established; and that thus facts of vegetable production are explained, which

otherwise remain unexplained. To this, and other points involved, I shall refer again presently.

Lastly, I have to summarise those of the results and conclusions of Boussingault, which bear upon the present aspect of the question of the sources of the nitrogen of vegetation. In his earlier experiments, as in those at Rothamsted, sterilised materials had been used as soils; but in 1858 he commenced a series in which more or less of a rich garden-soil was mixed with sand and quartz. In some cases the plants were grown in free air, and in others in closed vessels with confined air. In several cases there was more or less gain of nitrogen; but the greatest gain was in an experiment with a Lupin grown in a closed vessel. Boussingault points out that it was the soil and not the plant that had fixed the nitrogen. The result was so marked that he repeated the experiment in 1859, when he obtained almost identically the same amount of gain as in 1858. He also put 120 grams of the rich soil into a shallow dish, moistened it with distilled water, and exposed it to the air as an experiment on Fallow. The results showed a small gain of nitrogen.

Boussingault further found, that mycodermic vegetation went on in rich soil, and he considered the gains of organic nitrogen represented the remains of such vegetation; whilst the Fallow experiment indicated that the experimental plants had little to do with the action. His general conclusion was, that from the numerical results it must be believed, that the soil had fixed nitrogen; and he considered that, if there were no absolute proof, there was strong presumption, that the nitrogen of the air takes part in nitrification.

In the next year, 1860, he put into one large glass balloon a mixture of rich soil and sand, and into another a similar mixture, with cellulose in addition; each was moistened with distilled water, and the vessels were then closed up for 11 years. During this period, without cellulose rather more, and with cellulose rather less, than one-third of the nitrogen of the soil was nitrified; but in neither case was there any gain of total combined nitrogen. There was, indeed, in both cases, a slight loss of nitrogen indicated. Boussingault concluded that free nitrogen had not contributed to the formation of nitric acid.

The later results of Boussingault did not, therefore, confirm those he obtained in 1858 and 1859; and in answer to a letter from me he wrote in 1876, that he was not aware of any irreproachable observation which established the reality of the fixation of free nitrogen by the soil. He further stated his belief, that neither the higher plants, nor mycoderms, nor fungi (champignons), fix free nitrogen. He also maintained the same view in conversation in 1883.

SUMMARY AND GENERAL CONSIDERATIONS ON THE SOURCES OF THE NITROGEN OF OUR CROPS.

It did indeed seem that, in Boussingault's results of 1858 and 1859, there was *the germ of the germ theory* of the fixation of free

nitrogen, if such took place at all in connection with vegetation. But his own very distinct final conclusion against the supposition of such fixation by the agency of the lower organisms, seemed to indicate the necessity for caution in accepting much of the evidence which has been accumulating during the last few years.

It is evident that since experimenting with non-sterilised materials, and in free air instead of in closed vessels, has become more general, there has been a great accession of evidence which is held to show the fixation of free nitrogen. But, not only are the gains in some cases very small, and in others very large, but the modes of explanation are very different.

Thus, the various modes of explanation of the observed gains of nitrogen are:—that *combined* nitrogen has been absorbed from the air, either by the soil or by the plant; that there has been fixation of *free* nitrogen within the soil, by the agency of porous and alkaline bodies; that there has been fixation by the plant itself; that there has been fixation within the soil (or by the plant), by the agency of electricity; and finally, that there has been fixation under the influence of lower organisms, either within the soil itself, or in symbiotic growth with the higher plant.

The balance of the evidence recorded, is undoubtedly much in favour of the last mentioned mode of explanation. But of all the recent results bearing upon the subject, those of Hellriegel and Wilfarth, with certain leguminous plants, seem to be by far the most definite and significant. Accordingly, as we stated in October, 1888, in a postscript to our paper—“*On the Present Position of the Question of the Sources of the Nitrogen of Vegetation.*” (*Phil. Trans.*, 1889.)—it had been decided to institute somewhat similar experiments at Rothamsted. A preliminary series was, in fact, then in progress; and a more extended one has been undertaken in the present season, 1889. The results of these experiments show conclusively that, by the addition to the experimental soil, of a small quantity of the watery extract of a soil containing the appropriate organisms, there was greatly increased growth, and considerable gain of nitrogen; and there was, coincidentally, a considerable development of the so-called leguminous nodules on the roots of the plants.

The conclusion is, not that the leguminous plant had directly utilised free nitrogen; but that the gain was due to the fixation of nitrogen in the growth of the lower organisms in the root-nodules; the nitrogenous compounds so produced, being taken up and utilised by the leguminous plant. It would seem, therefore, that in the growth of leguminous crops, such as Clover, Vetches, Peas, Beans, Lucerne, &c., at any rate some of the large amount of nitrogen which they contain, and of the large amount which they frequently leave as nitrogenous residue in the soil for future crops, may be due to atmospheric nitrogen so derived. It has yet to be ascertained, however, under what conditions a greater or less proportion of the total nitrogen of the crop will be derived, on the one hand from nitrogen compounds within the soil, and on the

other from such fixation. The probability seems to be, that the proportion due to fixation will be the less in the richer soils, and the greater in soils that are poor in combined nitrogen, and which are open and porous.

Even assuming that, in the case of leguminous crops, there will generally be some gain of nitrogen due to the symbiotic growth supposed, it will nevertheless be well to consider the facts of agricultural production, in their bearing on the question of the sources of the nitrogen of crops generally.

As already said, much of the investigation that has been undertaken in recent years, has been instigated by the assumption that there must exist natural compensation for the losses of combined nitrogen which the soil suffers by the removal of crops, and for the losses which result from the liberation of free nitrogen from its combinations under various circumstances. In some cases, however, the object seems to have been for the most part limited to an attempt to solve the admitted difficulty as to the explanation of the source of the whole of the nitrogen of the Leguminosæ.

As to the losses which the soil sustains by the removal of crops, Berthelot, for example, assumes that 50 to 60 kilog. of nitrogen will be annually removed from a hectare of meadow (= 45 to 54 lbs. per acre); and that, as only 10 kilog., or less, of this will be restored as combined nitrogen in rain, &c., there will be an annual loss of from 40 to 50 kilog. per hectare (= 36 to 45 lbs. per acre); so that, if there were not compensation from the free nitrogen of the air, the soil would become gradually exhausted. Further, he considers that the fact of the fixation of free nitrogen, not only explains how fertility is maintained, but how argillaceous soils, which are sterile when first brought into contact with the air, gradually yield better crops, and at length become vegetable moulds. Frank, again, assumes that the average loss of nitrogen by the removal of crops is 51 kilog. per hectare (= 45 lbs. per acre).

It is quite true, that a good hay crop may contain as much as 50 to 60 kilog. of nitrogen per hectare; but it may safely be affirmed that, in ordinary practice, even in the case of an unusually fertile meadow, such an amount is not annually removed for a number of years in succession, without the periodical return of manure supplying nitrogen; whilst, taking the average of soils, the annual yield will seldom reach the amount supposed, even with the ordinary periodic return, and without such return gradual exhaustion would be very marked. Indeed, it is well known that there is no more exhausting practice than the annual removal of hay without return of manure; so that, in point of fact, restoration in anything like the degree supposed, certainly does not take place. Next to the removal of hay, the consumption of the grass for the production of milk is the most, but still very much less, nitrogen-exhausting; whilst, if grass be consumed by store or fattening animals, the loss is very much less still; indeed, it is then very small.

Obviously, however, it is more important to consider, what is the probable average loss of nitrogen over a given area by the removal of crops generally, and not by that of grass alone. Moreover, in making such an estimate, it is not the total nitrogen of the crops that has to be reckoned; but, taking into account the return by manure, only the amount eventually lost to the soil. With the great variation according to circumstances, it is of course very difficult to estimate this at all accurately; but it may be stated, that two independent modes of estimate lead to the conclusion that, for Great Britain for example, the average annual loss of nitrogen is more probably under than over 20 lbs. per acre (= 22.4 kilog. per hectare). In fact, the loss by cropping under the usual conditions of more or less full periodical return by manure, is by no means so great as is generally assumed in discussions of this subject.

The loss of nitrates by drainage may, however, in some cases be considerable. There may also, under some circumstances, be loss by the evolution of free nitrogen. Such loss may take place in the manure heap; or in soils very heavily manured, as in market gardening, for example. But in ordinary agriculture such excessive manuring seldom takes place; and the soil is generally much poorer in nitrogen than in the cases of the experiments which have been adduced as showing great loss from rich soils. Loss may also take place when the soil is deficiently aerated; but, here again, the conditions of the experiments cited, in which considerable loss by evolution of free nitrogen was observed, are not the usual conditions of soils in actual practice. Indeed, the balance of evidence is against the supposition that there is a constant and considerable loss by the evolution of free nitrogen from arable soils which are only moderately rich in organic nitrogen, and which are fairly drained, either naturally or artificially.

On this point it may be mentioned that, in those of the field experiments at Rothamsted in which the unusual practice of applying farm-yard manure every year is adopted, it is found that there is considerable loss of nitrogen from the soil, beyond that known to be removed in the crops, and estimated to be lost in the drainage.

On the other hand, where no nitrogen has been applied for many years, and the amount of nitrogen in the surface soil is only about, or little more than 0.1 per cent., the loss of nitrogen by the soil over a long series of years corresponded approximately with the amounts removed in the crops, together with those estimated to be lost in the drainage. Again, when ammonium-salts are applied, even so late in the season as October or November, and drainage takes place soon afterwards, the drainage-waters will contain amounts of nitrogen showing a very direct relation to the different amounts of ammonia applied in the manure; but scarcely any of it as ammonia, nearly the whole existing as nitric acid; and this is the case although the drainage passes through twenty inches or more of raw clay sub-soil. Lastly, direct experiments have shown that there is a diminution in the amount of nitric acid in the soil down to a certain depth, varying according to the

root-range of the crop grown, and to the season, but that in the depths of the sub-soil below this point, the amount is again greater.

Again, M. Berthelot thinks it probable, though not absolutely established, that there is loss of nitrogen from the plant itself during growth. Long ago, we supposed that there was such loss; but careful consideration of the evidence relating to the subject has led us to the conclusion that it is not proved, and to believe that it probably does not take place. It may be observed, that when in his vegetation experiments M. Boussingault found a loss of nitrogen, there was coincidently some decaying vegetable matter, such as fallen leaves; and in somewhat parallel experiments at Rothamsted, no loss of nitrogen was found as a coincident of growth, and in the absence of dead vegetable matter. Indeed, if there were such loss during growth when there was no decay, either in M. Boussingault's experiments or our own, it must have been almost exactly balanced by corresponding gain; an assumption which is without any proof, but which has nevertheless had its advocates.

In fact it may be concluded that, under the existing conditions of practical agriculture in temperate climates, the annual loss of combined nitrogen over a given area, by cropping and otherwise, is by no means so great as has been assumed; that the restoration required to compensate the loss is, therefore, correspondingly less; and further, that the known facts relating to the maintenance or the reduction of the fertility of soils, do not point to the conclusion that such loss as actually does take place, is compensated by such restoration.

The well known accumulation of nitrogen which takes place in the surface-soil within a few years, when arable land is laid down to grass, is, it may be admitted, not conclusively explained. At the same time, there is abundant experimental evidence pointing to the conclusion that some deep-rooted leguminous plants derive a considerable quantity of nitrogen from the sub-soil; and there seems no reason to doubt that the deep-rooting plants of the mixed herbage of grass-land, whether leguminous or otherwise, may also avail themselves of sub-soil nitrogen; and, if so, it is to be supposed that they, like clover for example, will leave nitrogenous crop-residue in the surface-soil, the nitrogen of which has been derived from the sub-soil. In reference to this point it may be observed, that at Rothamsted there is per acre, in soil and sub-soil, to the depth at which the action of some deep-rooted, and large nitrogen-accumulating plants, has been proved, a store of about 20,000 lbs. of already combined nitrogen. It is true that whilst many other soils and sub-soils will contain as much, or more, many will contain much less.

It is indeed pretty certain, that at any rate much of the nitrogen gained by the surface-soil of land newly laid down to grass, has its source in the combined nitrogen of the sub-soil. Obviously, however, in view of results showing that leguminous crops may acquire nitrogen brought into combination under the influence of the symbiotic growth of lower organisms, the question suggests itself whether part of the

nitrogen accumulated in the surface-soil of land laid down to grass may not be due to such an action. On this point it may be remarked, that the "*nodules*" have been observed on the roots of some Leguminosæ growing in the mixed herbage of grass-land. On the other hand, it has to be borne in mind, that the proportion of leguminous plants in such mixed herbage is comparatively small. Further, it has yet to be determined whether the source of the nitrogen of the bacteroids in the nodules is exclusively free nitrogen, when the development proceeds in soil and sub-soil containing a large amount of combined nitrogen.

As to the supposition that the gains of nitrogen in argillaceous matters of very low initial nitrogen-contents, and which are attributed to the fixation of free nitrogen, serve to explain the gradual formation of vegetable soils, there cannot be any doubt that, so far as nitrogen is concerned, the natural fertility of most soils is at any rate mainly due to the accumulation of ages of natural vegetation, with little or no removal of it, by animals or otherwise; and if the amounts of nitrogen even now brought into combination over a given area under the influence of electricity in equatorial regions, were not exceeded in the earlier periods of the history of our globe, that would probably be sufficient, with growth and with little or no removal, through the ages which modern science teaches us to reckon upon, to account for most, if not the whole, of the accumulations in natural grass, or forest lands; and it is these which have to a great extent furnished us with our meadows and pastures, and arable soils.

Frequently the natural forests have been on the more elevated, or the more undulating lands, and the soils they have formed are less rich than the prairie lands for the most part found in the valleys or on the plains. Taking the vast areas of fertile natural prairie on the American continent for example, sometimes of several feet in depth, it may be estimated that, in such cases, each foot of depth will contain from 6,000 to 10,000 lbs., or even more, of combined nitrogen per acre; and the probable time of these accumulations at any rate obviates the necessity of assuming the intervention of the free nitrogen of the atmosphere, brought into combination by the soil, or by the plants themselves. So far, however, as leguminous growth may have contributed to the result, it is, in view of existing evidence, to be supposed that some at any rate of the accumulation may have been due to fixation under the influence of the symbiotic growth of lower organisms and the higher plants.

Further, the history of agriculture so far as it is known, indicates that arable soils without supplies by manure from external sources, do, as a matter of fact, gradually become less fertile. This, as a rule will take place more rapidly in undulating or high forest lands, than in the natural grass or prairie lands of the plains.

Again, if we compare the amount of nitrogen in the surface-soil of permanent grass land, with that of adjoining land of the same original character, but which has for some time been under arable culture, we find that the latter is much poorer in nitrogen. In illustration, it may

be stated, that whilst the surface-soil of the grass land at Rothamsted contains from 0·25 to 0·30 per cent. of nitrogen, that of the corresponding arable land contains only from 0·1 to 0·15 per cent. The arable soil has, in fact, originally been covered with natural vegetation of some kind, with comparatively little removal, and consequent accumulation; whilst, under arable culture, much of the accumulated nitrogen has been used up, and the loss has not been compensated by free nitrogen brought into combination within the soil, either under the influence of electricity or of lower organisms. Indeed, whether or not there is any restoration of the kind supposed, a consideration of the origin of soils generally, and of the history of agriculture in different countries, leads to the conclusion that the losses of combined nitrogen by cropping, and in other ways, are not compensated by corresponding amounts of free nitrogen constantly brought into combination.

The Rothamsted Field Experiments have now been continued long enough to afford some pertinent examples bearing upon this subject.

Thus, in the case of the plots under continuous wheat, continuous barley, alternate wheat and fallow, and continuous root-crops, with mineral, but without nitrogenous manure, the average annual yield of nitrogen in the crops has only been about or under 20lbs per acre; the amount has declined to less than the average in the later years; and, coincidently with the continuous and diminishing growth, the percentage of nitrogen in the surface-soil has been considerably reduced. The loss by the removal of even such small crops, together with that by drainage, has, therefore, as a matter of fact, not been compensated by free nitrogen brought into combination, either by the plants, or within the soil.

In the field where the Leguminous crop—Beans, had been grown 25 years out of 32, with mineral but without nitrogenous manure, and had yielded less than average agricultural crops, the per-centage of nitrogen in the surface-soil was also greatly reduced.

In another field, where the Leguminous crop—Red Clover, had been sown 12 times in 30 years, the Clover failed many times, the yield of nitrogen in the crops very greatly diminished, and the per-centage of nitrogen in the surface soil was greatly reduced.

Again, in rich garden-soil, where Red Clover has been grown for 36 years consecutively, and has yielded throughout good, but gradually diminishing crops, it was found, after the first 22 years, that the nitrogen in the surface-soil had been reduced from 0·5095 to 0·3634 per cent., or by about one-third.

Even in an actual course of rotation, of Turnips, Barley, Clover or Beans, and Wheat, with mineral, but without nitrogenous manure, the per-centage of nitrogen in the surface-soil has been much reduced; whilst, in a parallel rotation in which Fallow takes the place of the Clover or Beans, the reduction is still greater.

Thus, in all the cases cited, including Gramineous, Cruciferous, Chenopodiaceous, and even Leguminous crops, and a rotation of crops, grown for many years in succession without nitrogenous manure, and yielding

comparatively small and declining amounts of nitrogen in the produce, there has, coincidentally, been a considerable reduction in the amount of nitrogen in the surface-soil. There has, in fact, not been compensation from the free nitrogen of the air, or at any rate not at all in amount corresponding to the annual losses.

Lastly, Grass-land which, under the influence of a full mineral manure, including potash, but without any supply of nitrogen for more than thirty years, has grown crops containing rather large amounts of comparatively superficially rooting leguminous herbage, which has been succeeded by increased amounts of gramineous herbage, and has, under those conditions, yielded about the same amount of nitrogen per acre as M. Berthelot assumes to be the average produce of a meadow, but it has done so, only with coincident great reduction in the nitrogen of the surface-soil.

Whether, therefore, we consider the facts of agriculture generally, or confine attention to special cases under known experimental conditions, the evidence does not favour the supposition that a balance is maintained by the restoration of nitrogen from the large store of it existing in the free state in the atmosphere. Further, our original soil-supplies of nitrogen are, as a rule, due to the accumulations by natural vegetation, with little or no removal, over long periods of time. Or, as in the case of many deep subsoils, the nitrogen is partly due to animal remains, intermixed with the mineral deposits. The agricultural production of the present age is, in fact, so far as its nitrogen is concerned, largely dependent on previous accumulations; and, as in the case of the use of coal for fuel, there is not coincident and corresponding restoration, so in that of the use or waste of the combined nitrogen of the soil, there is not evidence of coincident and corresponding restoration of nitrogen from the free to the combined state.

In the case of agricultural production for sale, without restoration by manure from external sources, a very important condition of the maintenance of the amount of nitrogen in the surface-soil, or of the diminished exhaustion of it, is the growth of plants of various range and character of roots, and especially of leguminous crops. Such plants, by their crop-residue, enrich the surface-soil in nitrogen. It is, as a rule, those of the most powerful root-development that take up the most nitrogen from somewhere; and this fact points to a sub-soil source. But, independently of this, which obviously may be held to be only evidence of the necessity of obtaining water and mineral matters from below, in amount commensurate with the capability of acquiring nitrogen, direct experimental evidence can leave no doubt that such plants do obtain at any rate much of their nitrogen from the sub-soil. The question arises—whether or not the whole of the nitrogen of our crops comes from combined nitrogen, in the soil and sub-soil, in manure, and in rain, &c., or whether part of it is in some way derived from the free nitrogen of the atmosphere? Cumulative evidence points to the conclusion that, in the case of our gramineous, our cruciferous, our chenopodiaceous, and our solaneous crops, free nitrogen is not the

source. Recently acquired evidence indicates, however, that it may, indirectly, be the source of at any rate some of the nitrogen of Leguminosæ. It would further seem, that the development of the organisms capable of bringing free nitrogen into combination, if not an essential coincident of the growth of some leguminous plants, is at any rate favoured by such growth.

RESULTS OF EXPERIMENTS AT ROTHAMSTED,
ON THE
QUESTION OF THE
FIXATION OF FREE NITROGEN;

BEING

(WITH ADDITIONS)

A LECTURE DELIVERED JULY 18, 1890,

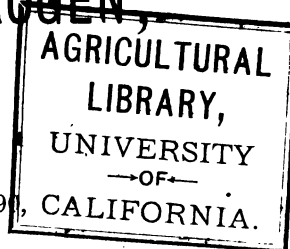
AT THE

ROYAL AGRICULTURAL COLLEGE,
CIRENCESTER,

BY

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HONORARY PROFESSOR OF THE COLLEGE.



FROM THE "AGRICULTURAL STUDENTS' GAZETTE."
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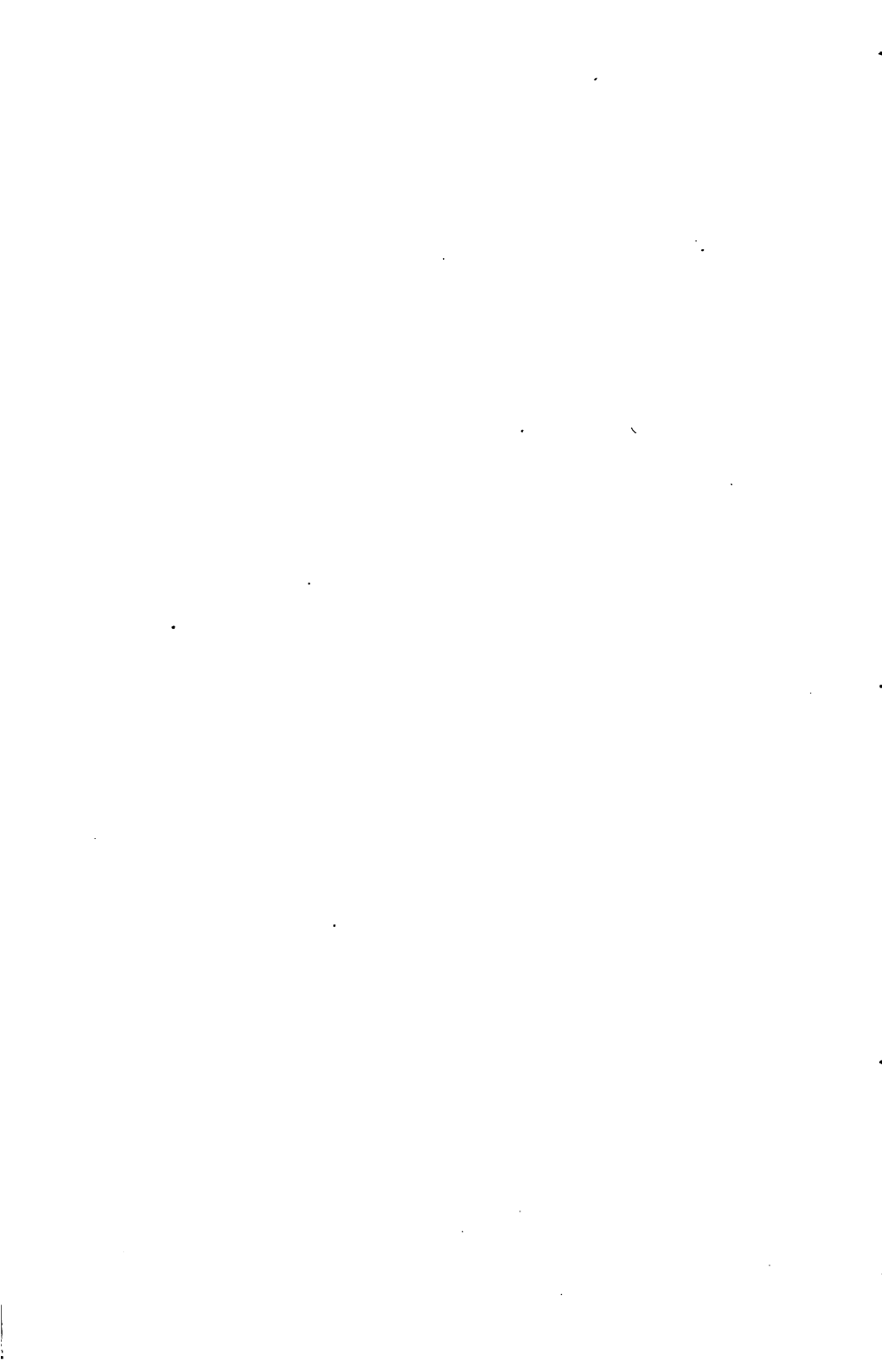
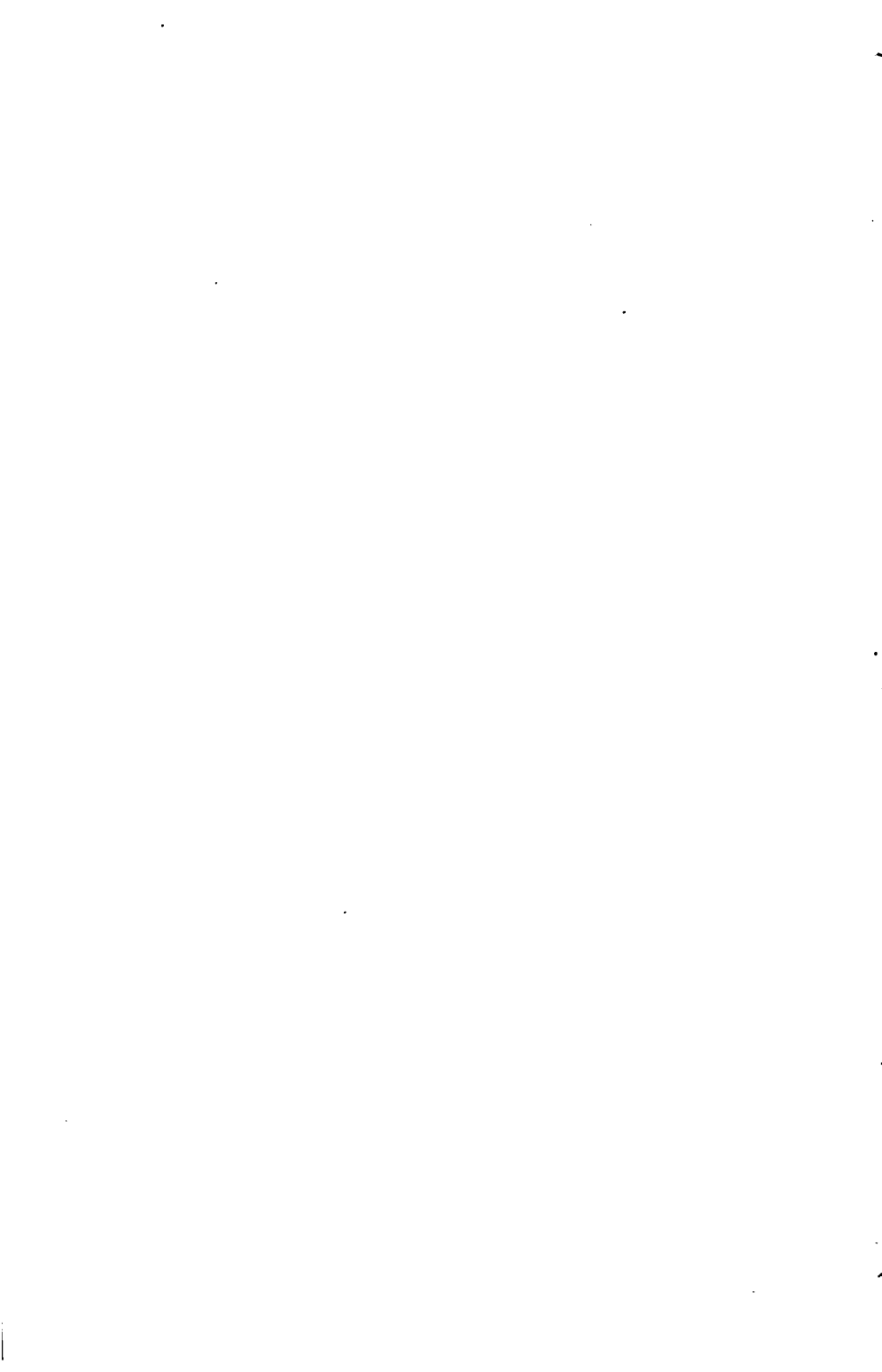


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RESULTS OF EXPERIMENTS AT ROTHAMSTED, ON THE QUESTION OF THE FIXATION OF FREE NITROGEN.

INTRODUCTION.

A large portion of the lecture on the conditions and results of growth of Leguminous Crops, which I gave at the College last year, was devoted to the illustration of the fact, that both the scientific interest, and the practical value, of those crops, depended very much on the amount of nitrogen which they contain, and on the sources of their nitrogen; and especially on the great differences in these respects, between them and the representatives of the other families with which they are grown, either in alternation in our rotations, or in association in our meadows and pastures. I then discussed the bearing of existing evidence on the question of the fixation of free nitrogen, and concluded by reference to some considerations and illustrations relating to the question of the sources of the nitrogen of crops generally.

With regard to the question of the fixation of free nitrogen, I stated—that nearly a century ago it was a matter of discussion whether plants took up, or evolved, free nitrogen; that it was just about half a century since Boussingault commenced experiments to determine whether plants did assimilate free nitrogen; that from his results he concluded that they did not; that results obtained at Rothamsted, about 30 years ago, confirmed those of Boussingault; but that others had come to an opposite conclusion.

During the last few years, however, the discussion has assumed a somewhat different aspect. The question still is whether the free nitrogen of the air is an important source of the nitrogen of vegetation; but whilst few now assume that chlorophyllous plants directly assimilate free nitrogen, it is nevertheless supposed to be brought under contribution in various ways; coming into combination—by the agency of electricity, within the soil, or within the plant; or under the influence of micro-organisms, or of other low forms, either within the soil itself, or in symbiotic growth with a higher plant.

The recent experiments, results, and conclusions, of Berthelot, Dehérain, Joulie, Dietzell, Frank, Hellriegel and Wilfarth, Emil von Wolff, and Atwater, were considered; as also were the later experiments of Boussingault in their bearing on an aspect of the question which has since come into prominence, namely, that of the fixation of free nitrogen within the soil under the influence of lower organisms.*

* For a fuller account of the results of Berthelot, and others, above referred to, and for references to their papers, see our paper in the "Philosophical Transactions," Vol. 180. B.

It was concluded that, of all the recent results bearing upon the subject, those of Hellriegel and Wilfarth, with certain leguminous plants, were by far the most definite and significant; and I stated that it had, accordingly, been decided to make experiments at Rothamsted on somewhat similar lines. I further stated, that a preliminary series had been undertaken in 1888, and a more extended one in 1889, and I exhibited photographs of some of the experimentally grown plants. Some of the numerical results have since been published, and they show a considerable fixation of free nitrogen. Much, however, still remains to be done; and many points necessary for drawing conclusions as to the practical importance of such fixation are as yet unsettled. The subject is, in fact, being further investigated at Rothamsted in the present year, 1890. I have, nevertheless, thought that enough was so far established, to supply material of sufficient interest for the subject of my present lecture: and, accordingly, I propose to bring before you to-day—*Results of Experiments at Rothamsted on the Question of the Fixation of Free Nitrogen.*

Before, however, describing the conditions and the results of the recent experiments, which do show a fixation of free nitrogen, it will be well to call attention to those of the earlier experiments, which did not indicate any fixation; as the well-defined difference in the conditions under which such different results were obtained, will bring clearly to view what are the conditions under which fixation does, and what are those under which it does not, take place. We shall thus, too, be the better able to form some judgment as to the practical bearing of the recent results.

THE EARLIER EXPERIMENTS, WHICH DID NOT SHOW FIXATION OF FREE NITROGEN.

I have already stated that the results and conclusions of Boussingault were against the supposition that plants assimilate the free nitrogen of the atmosphere. His numerous experiments on the subject were commenced in 1837, and were continued at intervals up to 1858. His soils consisted of burnt soil, washed and ignited pumice, or burnt brick; his experiments were sometimes in free air, in a summer house, sometimes in a closed vessel with limited air, sometimes with a current of washed air, and sometimes in free air, but under a glass case. When the plants were enclosed, a supply of carbonic acid was provided, and in a few cases known quantities of nitre were supplied as manure. In all, distilled water was used for watering. Thus, in all cases the substances he used as soil were sterilised; in some the supplied air was washed; whilst in others the plants grew in limited air, or were more or less protected. He experimented with a great variety of plants—wheat, and oats, representing Gramineæ; clover, peas, haricots, and lupins, as Leguminosæ; also garden cress and sunflower.

In some of his earlier experiments, conducted in free air in a summer house, the Leguminous plants, trefoil and peas, did indicate

some gain of nitrogen; but in all his subsequent experiments there was generally either a slight loss, or, if a gain, it was represented by only fractions, or low units of milligrams; the larger amounts being with Leguminosæ, in free air, under a glazed case. After 20 years of varied and laborious investigation of the subject, M. Boussingault concluded that plants have not the power of assimilating the free nitrogen of the atmosphere.

Experiments on the subject were commenced at Rothamsted in 1857, they were continued for several years, and the late Dr. Pugh took a prominent part in the enquiry.

The soils used were ignited, washed, and re-ignited pumice, or soil. The specially made pots were ignited before use, and cooled over sulphuric acid under cover. Each pot, with its plants, was enclosed under a glass shade, which rested in the groove of a specially made hard-baked glazed stoneware lute-vessel, mercury being the luting material. Under the shade, through the mercury, passed one tube for the admission of air, another for its exit, and another for the supply of water or solutions to the soil; and there was an outlet at the bottom of the lute-vessel for the escape of the condensed water into a bottle affixed for that purpose, from which it could be removed and returned to the soil at pleasure.

A stream of water being allowed to flow into a large stone-ware Woulff's bottle, of more than 20 gallons capacity, air passed from it, through two small glass Woulff's bottles containing sulphuric acid, then through a long tube filled with fragments of pumice saturated with sulphuric acid, and lastly through a Woulff's bottle containing a saturated solution of ignited carbonate of soda; and, after being so washed, the air entered the glass shade, from which it passed, by the exit tube, through an eight-bulbed apparatus containing sulphuric acid, by which communication with the unwashed external air was prevented. Carbonic acid was supplied as required by adding a measured quantity of hydrochloric acid to a bottle containing fragments of marble, the evolved gas passing through one of the bottles of sulphuric acid, through the long tube, and through the carbonate of soda solution, before entering the shade.

It will be observed that, by the arrangement described, the washed air was forced, not aspirated, through the shade, and the pressure being thus the greater within the vessel, the danger of leakage of unwashed air from without inwards was lessened.

In 1857, twelve sets of such apparatus were employed; in 1858 a larger number, some with larger lute-vessels, and shades; in 1859 six, and in 1860 also six.

Each year the whole were arranged, side by side, on stands of brickwork in the open air, as shown in the drawings of the apparatus exhibited. Drawings of some of the plants grown were also exhibited; and the numerical results obtained in the experiments of 1857 and 1858 are summarised in Table I.

The upper part of the Table (I.) shows the results obtained in 1857 and 1858, in the experiments in which no combined nitrogen was

supplied beyond that contained in the seed sown. The drawings exhibited showed how extremely restricted was the growth under these conditions, and the figures in the Table show that, neither with the Gramineæ, the Leguminosæ, nor the Polygonæ (buckwheat), was there in any case a gain of three milligrams of nitrogen. In most cases there was much less gain than this, or a slight loss. There was, in fact, nothing in the results to lead to the conclusion that either of these different descriptions of plant had assimilated free nitrogen.

TABLE I.

Summary of the Results of Experiments made at Rothamsted, in 1857 and 1858, to determine whether plants assimilate free Nitrogen.

				Nitrogen, Grams.		
				In Seed, and Manure if any.	In Plants, Pot, and Soil.	Gain or Loss.
WITH NO COMBINED NITROGEN SUPPLIED BEYOND THAT IN THE SEED SOWN.						
Gramineæ	1857	Wheat	0.0080	0.0072	— 0.0008	
		Barley	0.0056	0.0072	+ 0.0016	
		Barley	0.0056	0.0082	+ 0.0026	
	1858	Wheat	0.0078	0.0081	+ 0.0003	
		Barley	0.0057	0.0058	+ 0.0001	
		Oats	0.0063	0.0056	— 0.0007	
	1858	Wheat	0.0078	0.0078	0.0000	
		A* Oats	0.0064	0.0063	— 0.0001	
Leguminosæ	1857	Beans	0.0796	0.0791	— 0.0005	
	1858	Beans	0.0750	0.0757	+ 0.0007	
		Peas	0.0188	0.0167	— 0.0021	
Other Plants	1858	Buckwheat ..	0.0200	0.0182	— 0.0018	
WITH COMBINED NITROGEN SUPPLIED BEYOND THAT IN THE SEED SOWN.						
Gramineæ	1857	Wheat	0.0329	0.0383	+ 0.0054	
		Wheat	0.0329	0.0331	+ 0.0002	
		Barley	0.0326	0.0328	+ 0.0002	
		Barley	0.0268	0.0337	+ 0.0069	
	1858	Wheat	0.0548	0.0536	— 0.0012	
		Barley	0.0496	0.0464	— 0.0032	
		Oats	0.0312	0.0216	— 0.0096	
	1858	Wheat	0.0268	0.0274	+ 0.0006	
		Barley	0.0257	0.0242	— 0.0015	
A* Oats		0.0260	0.0198	— 0.0062		
Leguminosæ	1858	Peas	0.0227	0.0211	— 0.0016	
		Clover	0.0712	0.0665	— 0.0047	
Other Plants	1858	Beans	0.0711	0.0655	— 0.0056	
	1858	Buckwheat ..	0.0308	0.0292	— 0.0016	

* These experiments were conducted in the apparatus of M. G. Ville.

The lower part of the Table shows the results obtained in the experiments in which the plants were supplied with known quantities of combined nitrogen, in the form of a solution of ammonium-sulphate, applied to the soil. The drawings show very strikingly the effect of this direct supply of combined nitrogen, especially in the case of the Gramineæ. The figures in the Table show that the actual gains or losses of nitrogen range a little higher in these experiments, in which larger quantities were involved; but they are always represented by units of milligrams only, and the losses are higher than the gains. Further, the gains, such as they are, are all in the experiments with the Gramineæ, whilst there is in each case a loss with the Leguminosæ, and with the buckwheat. The losses, beyond such as might be expected from experimental error, are doubtless due to decay of organic matter, fallen leaves, &c.

It should be stated that the growth was far more healthy with the Gramineæ than with the Leguminosæ, which are, even in the open field, very susceptible to vicissitudes of heat and moisture, and were found to be extremely so under the conditions of enclosure under glass shades. It might be objected, therefore, that the negative results with the Leguminosæ are not so conclusive as those with the Gramineæ. Nevertheless, we concluded, and still conclude, from the results of our own experiments, as Boussingault did from his, that neither the Gramineæ nor the Leguminosæ assimilate the free nitrogen of the air.

That, under the conditions described, the Leguminosæ, as well as the Gramineæ, can take up and assimilate already combined nitrogen supplied to them, is well illustrated in the experiments made in 1860 with Leguminosæ alone. The series comprised three experiments with white Haricot beans—No 1 without any other supply of combined nitrogen than that in the seed, No. 2 with a fixed quantity of nitrogen applied as ammonium sulphate, and No. 3 with a fixed quantity supplied as nitrate; also 3 experiments with white Lupins—No. 1, as with the Haricots, without artificial supply of combined nitrogen, No. 2 with supply as ammonium-sulphate, and No. 3 as nitrate.

The drawings clearly showed that, with both descriptions of Leguminous plant, there was considerably increased growth by the addition both of ammonium sulphate and of nitrate. Owing, however, to the atmospheric conditions within the shade, as above referred to, the plants lost both leaves and flowers, and hence the drawings do not represent the full growth.

Such, then, were the negative results obtained when plants were grown under conditions of sterilisation and of enclosure. There was, under such conditions, no gain from free nitrogen, in the growth of either Gramineæ, Leguminosæ, or other plants.

RECENT EXPERIMENTS, WHICH DO SHOW FIXATION OF FREE NITROGEN.

I stated in my lecture last year, that it was about 1876 that M. Berthelot called in question the legitimacy of the conclusion that

plants do not assimilate the free nitrogen of the air, when drawn from the results of experiments in which the plants are so enclosed as to exclude the possibility of electrical action, and that he had more recently objected to experiments so conducted with sterilised materials, on the ground that, under such conditions, the presence, development, and action, of micro-organisms are excluded. It was pointed out that in the experiments of Berthelot, and some others, gains were found under very various conditions, that they were in some cases very small, and in others very large, and that the explanations of the gains were very various. I believe, however, that there is nothing in the recent results, either of Berthelot himself or of others, which can be held to invalidate the conclusion which had been drawn from the results of Boussingault, and from those obtained at Rothamsted, that the higher chlorophyllous plants do not directly assimilate free nitrogen.

Let us now consider what are the results obtained, when the conditions of growth involve neither sterilisation nor enclosure.

We have maintained that it can hardly be said that there remained an unsolved problem in regard to the source of the nitrogen of our *non*-Leguminous crops, but that it must be admitted, in spite of all the investigations and discussions of the last 50 years, that the source of the whole of the nitrogen of our Leguminous crops had not been satisfactorily explained. Hence, it was argued, evidence obtained on new lines should receive careful consideration. According to some recent experimenters, however, gain from the fixation of free nitrogen is not limited to our Leguminous crops. But, quite accordantly, not only with common experience in agriculture, but with the direct experimental results of ourselves and others, Hellriegel found in his experiments that plants of the gramineous, the chenopodiaceous, the polygonous, and the cruciferous families, depended on combined nitrogen supplied within the soil. On the other hand, he found that leguminous plants did not depend entirely on such supplies. His results were, indeed, not only very definite, but they had a special bearing on the admittedly unsolved problem of the source of the whole of the nitrogen of the Leguminosæ.

Accordingly, as already stated, we made experiments on the subject at Rothamsted in 1888 and 1889, and it is being further investigated in the present season, 1890. I propose to give, on the present occasion, a description, and some of the numerical results, of the experiments made in 1888; a description, and some illustrations of the growth, in 1889; and also a brief account of the experiments still in progress.

Hellriegel's experiments may be briefly described as follows:—in 1883 he commenced a comprehensive series of vegetation experiments in pots, in which he grew agricultural plants of various families in washed quartz sand. To all the pots nutritive solutions containing no nitrogen were added. To one series nothing else was supplied; to a second a fixed quantity of nitrogen as sodium-nitrate; to a third twice as much; and to a fourth four times as much. The result was that, in the case of the Gramineæ, and some other plants, the growth was

largely proportional to the nitrogen supplied, whilst in that of the Papilionaceæ it was not so. In the case of these plants, that of peas for example, it was observed that, in a series of pots to which no nitrogen was added, most of the plants were apparently limited in their growth by the amount of nitrogen which the seed supplied. Here and there, however, a plant growing under ostensibly the same conditions, grew very luxuriantly; and, on examination, it was found that whilst no nodules were developed on the roots of the plants of limited growth, they were abundant on those of the luxuriantly growing plants.

In view of this result, Hellriegel instituted experiments to determine whether, by the infection of the soil with appropriate organisms, the formation of the root nodules, and luxuriant growth, could be induced, and whether by the exclusion of such infection the result could be prevented. To this end, he added to some of a series of experimental pots 25 cc., or sometimes 50 cc., of the turbid extract of a fertile soil, made by shaking a given quantity of it with five times its weight of distilled water. In some cases, however, the extract was sterilised. In those in which it was not sterilised, there was almost uniformly luxuriant growth, and abundant formation of root nodules; but with sterilisation there was no such result. Consistent results were obtained with peas, vetches, and some other Papilionaceæ; but the application of the same soil-extract had no effect in the case of lupins, serradella, and some other plants of the family which are known to grow more favourably on sandy than on loamy or rich humus soils. Accordingly, he made a similar extract from a diluvial sandy soil where lupins were growing well, in which it might be supposed that the organisms peculiar to such a soil would be present; and, on the application of this to a nitrogen-free soil, lupins grew in it luxuriantly, and nodules were abundantly developed on their roots.

THE VEGETATION EXPERIMENTS IN 1888.

This preliminary series comprised experiments with peas, blue lupins, and yellow lupins. The peas were grown—

1. In washed sand, with the ashes of the plant added; but with no supply of combined nitrogen beyond a small determined amount in the washed sand, and that in the seed sown.
2. In similarly prepared sand, but seeded with 25 cc. of the turbid watery extract from a rich garden soil.
3. Duplicate of No. 2.
4. In the rich garden soil itself.

Each of the two descriptions of lupins was grown—

1. In sand prepared as for the peas, but with the lupin-plant-ash instead of pea-plant-ash added.

2. In similar washed sand, &c., but seeded with 25 cc. of the turbid watery extract from a sandy soil where lupins had grown luxuriantly.
3. In the lupin sandy soil itself.
4. In rich garden soil.

The twelve pots were arranged in a small greenhouse; and distilled water, free from ammonia, was used for watering.

The sand employed was a yellow sand, from Flitwick, in Bedfordshire, such as is used by gardeners for potting. The stones and coarser portions were removed by sifting, the remainder was several times washed, first with well-water, and afterwards with distilled; then dried in a water-bath, and finally mixed with the plant-ash. It still contained 0·00266 per cent. of nitrogen.

The sandy-soil from which the watery extract was made for microbe-seeding the pots where lupins were to grow, and which was used as the soil in experiment No. 3 with lupins, was obtained from land which had been reclaimed from a common in Suffolk, on which no corn crop would grow, but on which, when subsequently sown with blue lupins they grew as high as the hurdles. Excepting that visible organic matter was removed by sifting and picking, it was used as received, in which state it contained 0·0859 per cent. of nitrogen.

The garden-soil contained 10·12 per cent. of moisture, and 0·3919 per cent. of nitrogen, corresponding to 0·4360 per cent. on the soil dried at 100°C.

The pots used were made of glazed earthenware. They had a hole half an inch in diameter at the bottom for drainage, and another at the side, near the bottom, for aëration, into which a glass tube bent upwards, and lightly closed with cotton wool to exclude insects, was fixed. The pots rested on slips of thick sheet glass, placed in basins of the same glazed earthenware as the pots.

The plant-ashes used as mineral nutriment, were prepared by suspension in distilled water, adding sulphuric acid to the point of neutralisation, evaporating to dryness, and gently re-igniting.

The drain hole at the bottom of each pot was loosely covered with a piece of thick glass, and 1 lb. of broken, washed, and dried flint was then put in. The pots held from 7 to 9 lbs. of the yellow sand, from 6 to 7 lbs. of the lupin sand, and about $4\frac{1}{2}$ lbs. of the garden soil.

The soil extracts supposed to supply the organisms were made by shaking, in a stoppered bottle, 1 part of the garden soil or lupin sand, with 5 parts of distilled water, and, after subsidence, pouring off the turbid liquid, which was then passed through platinum gauze to separate any floating matter. Determinations of nitric nitrogen by Schlæsing's method, and of total nitrogen by copper-oxide, showed that the 25 cc. of the garden-soil extract used for seeding contained little more than $\frac{3}{4}$ of a milligram, and the 25 cc. of the lupin sand extract, little more than $\frac{1}{4}$ of a milligram, of nitrogen; quantities which are quite immaterial considered as a supply of combined nitrogen.

The seeds were selected for sowing and for analysis by weighing 3 or 4 lots of 100 each to ascertain the average weight per seed, and then a number of single seeds weighing within 5 milligrams of the mean weight were taken.

It was intended to commence the experiments early in the summer; but owing to the pressure of other work the necessary preparations were not completed until early in August. All the seeds were sown on August 6; 3 accurately weighed seeds being put into each pot.

From the first the peas germinated and grew well in each of the 4 pots; but in each of the 4 of blue lupins, and in each of the 4 of yellow lupins, one or more seeds failed, and had to be replaced; and in some cases these also failed. It is admittedly very difficult to secure healthy growth with lupins in pots. One essential condition seems to be that the soil must be kept open and porous; and it is also important that the mineral matter added to the soil should be quite neutral.

The failures with the lupins are well illustrated by the fact that, in spite of the re-sowings, there were, eventually, of blue lupins 3 plants in pot 1 with the yellow sand without soil-extract seeding; only 2 in pot 2 with the same sand and soil-extract seeding; none in pot 3 with the lupin sand itself, from which the soil-extract was prepared; and 3, but of very varying size, in pot 4 with garden-soil.

Then of yellow lupins there were only 2 plants in pot 1 with the yellow sand; only 2 in pot 2 with the sand and the lupin soil-extract seeding; only 2 in pot 3 with the lupin sand itself; and only 2 in pot 4 with the garden-soil.

Thus, in the preliminary experiments of 1888, with neither blue nor yellow lupins was the growth satisfactory; whilst, as will be seen further on, it was far otherwise, at any rate with yellow lupins, in 1889. I will not, therefore, take up time with any detailed discussion, either of the growth, of the root-development, or of the analyses, of the lupins of 1888; but I will now direct attention to the more satisfactory results obtained with peas in 1888, which, it will be seen, afford very important indications.

The Results with Peas, in 1888.

As already said, the peas in each of the four pots germinated and grew well. Those in the garden-soil were throughout the most luxuriant. Pots 2 and 3 were each seeded with 25 cc. of the garden-soil extract on August 13, that is just a week after the sowing of the seed.

For some time the plants in pot 1, in the sand without soil-extract, showed more growth, and better colour, than those in either pot 2 or pot 3 with the soil-extract seeding. It was, in fact, not until four or five weeks after the seeding with the soil extract, that the plants in pots 2 and 3 began to show a darker green colour than those in pot 1 without soil-extract. The indication was, however, so striking that, on September 25, it was decided to count the leaves, and to estimate, approximately, the relative area of leaf-surface, of the plants in the different pots. For this purpose the leaves were classified into those

which were bright green, those which were changing colour, and those which were withered. It will suffice to show the number, and the estimated relative area, of the total leaves in each case, on September 25, when the first counting and estimates were made, on October 17, on November 14, and on December 14 when the plants were cut. The following table summarises the results.

TABLE II. PEAS, 1888.

Total number of leaves, and estimated relative leaf surface, those of the plants in Pot 1 (without soil-extract seeding) on September 25, being taken as 100.

	Number of leaves.				Estimated relative leaf surface.			
	Pot 1	Pot 2	Pot 3	Pot 4	Pot 1	Pot 2	Pot 3	Pot 4
September 25..	144	140	120	164	100	67	58	128
October 17 ..	188	200	184	216	143	172	158	242
November 14..	244	300	244	280	170	249	245	328
December 14..	382	540	390	434	267	481	434	463

Thus, on September 25, after the plants in pots 2 and 3, with the soil-extract seeding, had begun to show a darker green colour, they nevertheless showed both a less number of leaves, and considerably less leaf-surface, than the plants in pot 1 without the soil-extract. It is not very clear why the plants with the soil-extract seeding remained so long in a comparatively backward condition. It may have been only accidental, depending on the character of the seeds, or on the fact that pot 1 stood at the southern end of the row, and nearest the glass. An alternative is that, in the early stages of the development of the nodules and their contents, the growth of the higher plant is in some way retarded. The figures show, however, that from this date, the plants in pots 2 and 3 with the soil-extract, gradually gained upon those in pot 1 without it, both in number of leaves and in leaf-surface; until, when the plants were taken up on December 14, those in pots 2 and 3 showed 540 and 390 leaves, against only 382 on those in pot 1; and 481 and 434 of leaf-surface, against only 267 in pot 1. There is, therefore, clear evidence of increased growth under the influence of the soil-extract seeding.

In all the pots the upper portions of the plants obviously developed at the expense of the lower, the leaves of which gradually lost colour, and withered, whilst the stems and leaves of the upper portion increased in growth; those in pots 2, 3, and 4, continuing to vegetate and to maintain a bright green colour to the last, whilst those in pot 1 showed more exhaustion, and maintained much less colour. Probably owing to the lateness of the season, there was no indication of flowering in any of the pots.

As the roots had to be preserved without any loss, for analysis, the examination of them had to be very carefully conducted, and was necessarily more restricted than if examination had been the only object. After the above-ground growth had been cut off, the pots, with their moist soil and roots, were kept in a warm dry place until the

examination commenced. The block of soil was carefully turned out on to glazed cartridge paper, and notes were at once taken as to the distribution of roots so far as it was then apparent. The sand or soil was then removed little by little until the roots were left nearly bare. Further notes were then taken, the remaining sand or soil was removed as far as possible by washing in a beaker with a little distilled water. The roots were then spread out upon paper, and so photographed, and finally noted upon.

The four pots of plants were photographed on September 1, September 22, October 6, and lastly on November 3, about five weeks before the taking up of the plants. Enlarged photographs of the plants at the last mentioned date, and of the roots when taken up as above described, were exhibited.

When due allowance is made for the difference in colour of the stems and leaves, as above described, the photographs of the plants are consistent in their indications with the results given in Table II., and with those which follow as to the relative amounts of dry matter produced, and of nitrogen taken up.

The indications of the enlarged photographs of the roots of the plants are of much interest.

The roots in pot 1, with the washed but not sterilised yellow sand, showed a densely matted mass of fibre, by far the greater portion of which was accumulated within the top four inches of the sand; and, notwithstanding there was no soil-extract seeding, there were many nodules on the roots, but fewer, and generally much smaller, than on those grown with the soil-extract seeding; they were also less characteristically accumulated near the surface, and more distributed along the root fibres. There were, however, some agglomerations of nodules. Comparing this result with that obtained in 1889, with a purer and sterilised sand, in which case there were no nodules, there can be little doubt that the development of nodules, and the comparatively luxuriant growth, in this pot without soil-extract seeding, are to be attributed to the impurity and non-sterilisation of the sand.

The roots in pot 2, with soil-extract seeding, also showed a dense mass of fibre, which, however, extended from the top to the bottom of the soil, penetrated the layer of flints, and distributed over the bottom of the pot. The roots were, in fact, much more generally distributed throughout the soil, and less accumulated within the surface layers, than in pot 1. The most developed root had three large agglomerated nodules, each with some scores of protuberances, somewhat as on a raspberry or mulberry. The other plants also showed similar nodules, but of a smaller size. There were also a number of small clusters distributed over the rootlets, but very few single nodules; differing in this respect from the development observed in pot 1.

In pot 3, also with soil-extract seeding, each of the three plants developed a mass of root-fibre extending throughout the soil, but less near the bottom. There were large agglomerations of nodules on the roots of each plant. There were, besides, many small clusters, and here

and there single nodules. By far the most of the nodules were within the top three inches of the sand, but one considerable bunch was found as low as four inches from the surface. As in the other cases, the nodules were grey, and much lighter in colour than the roots on which they grew.

Each of the three plants in pot 4, with the garden soil, had a stouter main root than any of those in the other pots. From the side branches there proceeded a large amount of fine root-fibres which extended throughout the whole soil, those from the different plants being much interwoven. The roots extended round the sides, and along the bottom of the pot, much more than in either of the other pots. There were three small clusters of nodules on the roots of each of the three plants, one or two small bunches, and here and there a single nodule. But the clusters were much smaller, the total number of nodules was much less, and they were more distributed throughout the soil, in this pot with rich garden soil, than in either of the others, even than in pot 1 without soil-extract seeding. The root development was, however, as the description shows, much greater than in either of the other pots. That is to say, there was, in this case, not only a greater development of root and root-fibre, but a less development of root nodules, in the soil which itself supplied an abundance of combined nitrogen, as well as other nutriment.

Upon the whole, then, the evidence relating to the peas clearly shows that there was a greatly enhanced development of nodules on the roots under the influence of the soil-extract seeding, and, coincidentally with this, considerably increased growth.

The Analytical Results.

The nitrogen was determined in the sand and in the garden soil, at the commencement and at the conclusion of the experiments; also in the seed, in the above-ground growth (stems and leaves), and in the roots, separately. The dry matter and ash were also determined, in the seed, and in the produce grown.

It is of interest to remark, that the percentage of ash in the dry substance of the more normally developed plants grown in the garden soil, was much less than in that of the plants grown in the sand with plant-ash added; also that the plants in pot 1, with the most restricted growth, and which from their pale colour indicated nitrogen-exhaustion, showed a lower percentage of nitrogen in the dry substance of both the above-ground and under-ground produce, than was found in that of either of the other pots. It may be added that the roots in pots 2 and 3, with the soil-extract, and with so much greater development of nodules than on those in either pots 1 or 4, also contained a considerably higher percentage of nitrogen in their dry substance.

The next Table (III.), shows the actual quantities of dry substance, and of nitrogen, in the separated, and in the total, products of growth.

It is seen that there is more dry substance in the above-ground growth, but less remaining in the roots, in pots 2 and 3 with the soil-

extract, than in pot 1 without it. In the whole plant, there is about 10 grams of dry substance in pot 1 without soil-extract, against about $11\frac{1}{2}$ grams in pot 2, and more than 11 grams in pot 3, each with soil-extract.

TABLE III. PEAS, 1888.

	Dry Substance.			Nitrogen.		
	In stems and leaves.	In Roots.	In whole plant.	In stems and leaves.	In Roots.	In whole plant.
Pot 1. Sand without soil-extract	grams. 7.423	grams. 2.600	grams. 10.023	gram. 0.2153	gram. 0.0689	gram. 0.2822
Pot 2. Sand with soil-extract	9.368	2.409	11.777	0.4591	0.0770	0.5361
Pot 3. Sand with soil-extract	9.411	1.748	11.159	0.3770	0.0687	0.4357
Pot 4. Garden soil	12.808	2.846	15.654	0.5806	0.0794	0.6600

The point of chief interest is, however, that there was in one case more than twice, and in the other nearly twice, as much nitrogen in the above-ground growth in pots 2 and 3 with the soil-extract seeding, as in pot 1 without it. But there was much less difference in the amounts remaining in the roots under the different conditions. Of nitrogen in the total vegetable matter grown, there is, in pot 2 nearly twice, and in pot 3 more than $1\frac{1}{2}$ time as much as in pot 1 without the soil-extract. In pot 4 with garden soil, and therefore full supply of already combined nitrogen, there was more dry substance produced, and more nitrogen assimilated, than under the influence of the soil-extract seeding.

The significance of the results relating to the nitrogen is, however, more clearly seen in the next Table (IV.), which shows—the amounts in the soil at the commencement and at the conclusion of the experiment, and the gain or loss; the amounts in the seed, in the total products of growth, and the gain; the total nitrogen in the soil and seed at the commencement, in the soil and produce at the conclusion, and the gain. The Table also shows, in the last column but one—the nitrogen in the total products reckoning the total initial nitrogen = 1; and in the last column, the amount in the plants, reckoning that in the seed = 1.

TABLE IV. PEAS, 1888.

	Nitrogen.									
	In Soil.			In Seeds and Produce.			Total.			In total products, total initial = 1.
	At commencement.	At conclusion.	Gain (+) or loss (-)	In Seeds Sown.	In total Plants.	Gain.	At commencement.	At conclusion.	Gain.	
Pot 1	grams. 0.0999	0.1096	+ 0.0097	gram. 0.0293	0.2822	0.2529	grams. 0.1292	0.3913	0.2621	3.03
Pot 2	0.0999	0.0974	- 0.0025	0.0298	0.5361	0.5063	0.1297	0.6335	0.5038	4.88
Pot 3	0.0999	0.0848	- 0.0151	0.0291	0.4357	0.4066	0.1290	0.5205	0.3915	4.04
Pot 4	7.9989	7.9989	—	0.0301	0.6600	0.6299	8.0290	8.6589	0.6299	1.08

The first point to notice is, that there is very little difference in the amount of nitrogen in the soils at the commencement and at the conclusion of the experiments. There would, doubtless, be some fine root-fibre not removed at the conclusion, so that where there is loss it is to be supposed that some of the original nitrogen of the soil has contributed to the growth. In the case of the garden-soil, with its high percentage of nitrogen, it is of course not impossible that there may have been some loss by the evolution of free nitrogen.

That there is at any rate no material gain of nitrogen in the soils would seem to be confirmatory of the conclusion indicated by other evidence, that the fixation is not effected by the organisms within the soil, independently of the symbiotic growth of the nodules and their contents, and of the higher plant to which they are attached, and to whose nitrogenous supply they seem to contribute. Indeed, if the fixation had taken place under the influence of microbes within the soil, independently of connexion with the higher plant, we should have to conclude that the latter had, nevertheless, availed itself of exactly the whole of the nitrogen so brought into combination—a supposition for which there would seem no reasonable justification.

Turning to the middle division of the Table, which shows the nitrogen in the seed sown, in the total vegetable matter grown, and the gain, and disregarding the changes in the soil itself, which it has been seen may well be done, it will be observed that, in the case of pots 1, 2, and 3, with sand, the gain in the plants is so large as to be very far beyond the limit of any possible experimental error. This certainly cannot be said of some of the experiments conducted on other lines, the results of which have been published in recent years, and have been held to show the fixation of free nitrogen under the agency of micro-organisms within the soil, without coincident higher plant-growth, or with the coincident growth of other plants than of the Leguminous family.

The gain in these initiative experiments with peas is, however, much less than in many of those of Hellriegel and Wilfarth. This is not to be wondered at, when the late period of the season, and the consequent character of the growth, are borne in mind; and when we come to consider the greater growth attained in the experiments of 1889, little doubt can be entertained that the fixation was then very much greater than it was in 1888.

To refer to the figures, it is seen that, whilst the nitrogen supplied in the seed was only 0.03 gram or less, that in the products of growth was 0.2822 gram in pot 1, 0.5361 in pot 2, 0.4357 in pot 3, and 0.6600 in pot 4; and the gains were more than $\frac{1}{4}$ of a gram in pot 1, more than $\frac{1}{2}$ a gram in pot 2, about $\frac{2}{3}$ ths of a gram in pot 3, and more than $\frac{3}{4}$ ths of a gram in pot 4.

The third division of the table shows—the total nitrogen at the commencement (in soil and seed together), at the conclusion (in soil and total vegetable matter grown), and the gains.

But the significance of the results is more clearly seen in the last

two columns. The first of these shows the relation of the amount of nitrogen in the total products (soil and plants together), to the total initial nitrogen (soil and seed together), taken as 1. It is seen that, even in pot 1, with the impure and not sterilised sand, but without soil-extract, there was, so reckoned, more than three times as much nitrogen in the products as in the soil and seed; in pot 2, with soil-extract, there was nearly five times as much; and in pot 3, also with soil-extract, there was more than four times as much. In the case of pot 4, however, with garden soil, owing to the large amount of initial nitrogen in the soil, the gain, though actually large, appears, when so reckoned, but small.

It is in the last column of the table, in which, disregarding the nitrogen in the soils, which was so nearly the same at the beginning and at the end, and reckoning the relation of the nitrogen in the total products of growth to that in the seed taken as 1, that the large amount of fixation is clearly brought to view. So reckoned, the nitrogen in the substance grown to that in the seed sown, was—in pot 1, $9\frac{1}{2}$ fold; in pot 2, nearly 18 fold; in pot 3, nearly 15 fold; and in pot 4, nearly 22 fold.

Here, then, under non-sterilised conditions, in fact with suitable microbe infection, there was very considerable fixation of free nitrogen.

THE VEGETATION EXPERIMENTS IN 1889.

In this second season a more extensive series was arranged. The plants selected were—peas, vetches, red clover, blue lupins, yellow lupins, and lucerne. For the lupins and lucerne, specially made pots of glazed earthenware were employed. They were about 6 inches in diameter, and 15 inches deep inside, that is about twice as deep as those used in 1888, and again for the peas, vetches, and red clover, in 1889. These pots had holes at the bottom for drainage, and slits at the side, near the bottom, for aëration. Each of the pots stood in a specially made pan of the same material. A quantity of broken, washed, and this time ignited flint, was put into the bottom of each pot. The sand used was a rather coarse, white quartz sand, from which the coarser and the finer portions were removed by sifting, and more of the finer by washing and decantation, first with well, and afterwards with distilled, water. In defect of means for igniting so large a quantity of material (about 300 lbs. in all) without running the risk of gaining more impurity than was expelled, the portion retained for use was kept, in successive lots, in a large water-bath, at nearly 100°C , for several days, and then preserved in well closed bottles. The results will show that the sand so prepared was sufficiently, if not absolutely, sterilised.

In each case the sand was mixed with 0.1 per cent. of the plant ash, and 0.1 per cent. of calcium carbonate; though much smaller quantities have since been used.

There were four pots of each description of plant. Of the peas,

vetches, red clover, and lucerne, No. 1 was with the prepared quartz sand without soil-extract ; No. 2 with the quartz sand and garden-soil-extract added ; No. 3 was duplicate of No. 2 ; and No. 4 was with the garden-soil itself. Of the blue and yellow lupins, No. 1 was with the prepared quartz sand without soil-extract ; No. 2 with lupin-soil-extract added ; No. 3 was duplicate of No. 2 ; and No. 4 was with the lupin soil itself, to which 0.01 per cent. of the plant-ash was added.

The soil-extracts were added the day before the sowing of the seed ; 25 cc. in the case of the peas, vetches, and red clover, and 50 cc. in that of the lupins and lucerne.

The seeds, selected and weighed as in 1888, were sown on July 10, that is, about four weeks earlier than in 1888, but still not so early as was desirable. In the case of the red clover ten seeds were sown in each pot ; in that of the blue and yellow lupins three, and in that of the peas, vetches, and lucerne, only two seeds, were put in each pot.

In all four pots, the peas germinated and grew well from the beginning. In the No. 1 pot of vetches, one seed failed, and had to be replaced. Several of the red clover seeds failed, and eventually four plants only were left in each pot. As in 1888, most of the blue lupins failed, and eventually only one plant, in only one of the four pots, remained. Some of both the yellow lupins and the lucerne also failed ; but, as will be seen further on, eventually two good plants remained in each pot.

The analytical details relating to the experiments of 1889 are not yet available ; but the notes on growth, and the photographs of the plants and of their roots, convey a clear idea of the importance and significance of the results obtained.

The Experiments with Peas, in 1889.

The peas were taken up on October 23 and 24. Photographs of the four pots of plants were taken on August 3, August 20, September 27, and lastly on October 22, that is the day before taking up ; and an enlargement of the last taken was exhibited. Unlike the result obtained in pot 1 in 1888 with impure and non-sterilised sand, the plants of 1889, in the purer and sterilised quartz sand, showed extremely limited growth. Before the end of July, those in both pots 2 and 3, with soil-extract seeding, began to show enhanced growth compared with that in pot 1, without the soil-extract ; and, eventually, whilst the plants in pot 1 were only $8\frac{1}{2}$ and $8\frac{1}{2}$ inches in height, those in pot 2, with soil-extract, were 14 and $50\frac{1}{2}$ inches ; and those in pot 3, also with soil-extract, were $52\frac{1}{2}$ and $50\frac{1}{2}$ inches high. In pot 4, with the garden soil, the plants showed even somewhat less extended growth than those in pots 2 and 3 with the soil-extract only. But the plants in pot 4 were more vigorous, and whilst they flowered and seeded, neither of those in either pot 2 or pot 3 did so ; but continued to vegetate, the upper parts apparently at the expense of the lower.

Then as to the root development :—in pot 1, without soil-extract, it

was altogether much less than in either pot 2 or pot 3 with soil-extract, or than in pot 4 with garden soil. Enlarged photographs of the roots clearly illustrated this. It was further seen that, in pot 1, without soil-extract seeding, the main roots descended some distance before they threw out any considerable amount of root-branches and root-fibre; whereas, in pots 2 and 3, with soil-extract, there was characteristically much more fibre distributed, both in the upper layers, and throughout the pot.

It is specially to be noted that, whereas in pot 1 in 1888, with impure and non-sterilised sand, there was a considerable development of nodules, now in the pure and sterilised sand, not a nodule was observable.

In pot 2, with soil-extract seeding, one plant was very much larger than the other, and developed very much more root. The smaller plant had, however, several nodules on the main root, near the surface of the soil, and a good many small ones distributed along the fibres. Most of the nodules were more or less shrivelled. The larger plant had a large cluster of nodules on the main root, very near the surface; and a very large number of single nodules, mostly small, was distributed on the root-fibres, quite to the bottom of the pot. Upon the whole those on the larger plant were less shrivelled.

In pot 3, also with soil-extract, the main roots extended to, and along, the bottom of the pot; throwing off many side branches, with a very large quantity of fine fibrous root. The greatest distribution was, however, in the upper few inches of the soil. There were two clusters of nodules on one of the plants, and three on the other, besides smaller bunches. A large number of mostly single small nodules was also distributed along the roots. On one of the plants the largest cluster was on the main root, and on the other the clusters were on the side branches.

In pot 4, with the garden soil, there was a dense mass of root-fibre throughout the first six inches of depth. There were numerous nodules, the majority single, and within the upper two or three inches of soil. There were also a few small bunches.

Thus, then, the limited growth in pot 1, without soil-extract, is coincident with the entire absence of nodule-formation; and the increased growth in pots 2 and 3, with soil-extract, is coincident with a very great development of nodules. In pot 4, with garden soil, itself supplying abundance of nitrogen, there was also a considerable development of nodules, but distinctly less than in either pot 2 or pot 3, with soil-extract only.

The Experiments with Vetches, in 1889.

The vetches were taken up on October 26. They had been photographed on August 3, August 20, September 27, and lastly on October 25, that is, the day before taking up; and of this last representation an enlargement was exhibited.

As with the peas, the plants in pots 2 and 3, with soil-extract, had, before the end of July, shown more growth than those in pot 1 without it. Again, as with the peas, the vetches in the pure and sterilised sand showed extremely limited growth. On the other hand, those in pots 2 and 3, with the soil-extract, grew to a very great height; indeed, higher than those in pot 4 with the garden soil.

The heights of the plants were—in pot 1, without soil-extract, $11\frac{1}{2}$ and $10\frac{1}{2}$ inches; in pot 2, with soil-extract, $52\frac{1}{2}$ and 67 inches; in pot 3, also with soil-extract, $61\frac{1}{2}$ and 51 inches; and in pot 4, with garden soil, only 53 and 36 inches.

But, as in the case of the peas, whilst the plants in pot 4 with the garden soil flowered and seeded, those in pots 2 and 3, with the soil-extract only, did not, but continued to extend upwards at the expense of the lower parts of the plant.

In pot 1, without soil-extract, there was much less development of root than in either pot 2 or pot 3 with it, or than in pot 4 with the garden soil. The main roots descended to the bottom of the pot, and threw out a number of side branches, but there was a marked deficiency of root-fibre. Not a single nodule was found.

In pot 2, with soil-extract seeding, there was a dense mass of root and root-fibre, which distributed throughout the whole of the soil, though the greatest accumulation was within the first three inches of depth. There were numerous nodules, but considerably less in quantity than on the corresponding pea plants. They were mostly single, the greater number being found in the lower layers, which is also contrary to the result with the peas. They were, moreover, generally exceedingly small.

In pot 3, also with soil-extract, there was also an immense development of root and root-fibre through the whole area of the soil; the greatest accumulation being in the upper and lower portions of the pot, with less in the middle. There were many nodules, but very small, and probably fewer than on the roots in pot 2. All the nodules were single, and fairly distributed over the whole root area.

In pot 4, with garden soil, there was a moderate amount of root and of root-fibre, chiefly within the upper six inches of depth; but there was altogether very much less of root development than in either pot 2 or 3 with the soil-extract. There were many nodules, but all single, and very small; and they appeared to be flattened, as if exhausted of their contents.

Here, then, with the vetches, as with the peas, the very restricted growth in pot 1, without soil-extract seeding, was associated with very limited root development, and with the entire absence of nodule-formation. On the other hand, the very greatly extended vegetative growth in pots 2 and 3, with soil-extract, was associated with an immense development of root and root-fibre, extending throughout the pots, and with the formation of numerous nodules; which, however, were generally smaller, more distributed over the whole root area, and less accumulated near the surface, than in the case of the peas. Lastly,

in the garden soil, with its liberal supply of combined nitrogen, there was much less development of roots, and less also of nodules, than in the pots with soil-extract only.

The Experiments with Lupins, in 1889.

It has already been said that most of the blue lupins failed; but it was with the yellow lupins that the most striking of all the results were obtained.

As in the case of the other plants, the yellow lupin seeds were put in on July 10, three being sown in each pot. There were some resowings, some seeds taken out, and, eventually, two plants were left in each pot. By the end of July, those in pots 2 and 3 with the lupin-soil-extract seeding, already showed more growth than those in pot 1 without it. Photographs were taken on August 3, August 20, September 27, October 28, and November 29; and the plants were cut on December 7. An enlargement of the photograph taken on October 28 was exhibited.

It was seen that the plants in pot 1, without soil-extract seeding, scarcely appeared over the rim of the pot, one being only about $1\frac{1}{2}$, and the other about $2\frac{1}{2}$ inches high. In pot 2, with lupin-soil-extract seeding, one plant was about 2 feet, and the other more than $1\frac{1}{2}$ foot high; both spreading much beyond the width of the pot. In pot 3, also with lupin-soil-extract seeding, one plant was more than 2 feet, but the other little more than 8 inches high. In fact, in both these pots with soil-extract seeding only, the plants showed considerably more development than those in pot 4 in the lupin-soil itself; one of these being only about 16, and the other about 18 inches high, and both less branching than those in pots 2 and 3.

Unlike the peas and vetches, the yellow lupins with soil-extract seeding only, flowered and podded freely. One plant in pot 2 had nine small pods; and one in pot 3, four large and three small ones. There were also in pot 4, with lupin-soil, on one plant five pods, and on the other six.

Thus, in the quartz sand with lupin-soil-extract seeding, the plants not only produced a great deal more vegetable matter than those in the lupin-sand itself, but they as freely flowered and seeded.

Examination, and the photographs of the roots of the plants showed that in pot 1, without soil-extract, and very restricted above-ground growth, there was coincidently very little root development. The main roots descended far down the deep pot almost without branching, but at the bottom a number of branches, and a mass of fibre were produced. The root-fibres were fleshy and succulent. No root swellings or nodules were found.

In pot 2, with the lupin-soil-extract seeding, there was, on the other hand, a very great development of root. Branches were thrown out throughout the whole length; and at their ends masses of fleshy fibrils were formed, which were thickly coated with root-hairs. On the

main root of one plant, 3 inches down, there was a large swelling or nodule the size of a field bean; 4 inches lower there were three smaller ones on a side branch; 10 inches down there were three as large as peas; and lower still there was another small swelling, more like the nodules found on other plants. The other plant had less root growth. One and a half inch down there was a swelling the size of a small pea; and $4\frac{1}{2}$ inches lower there were three swellings, one as large as a bean, and the others about the size of a vetch seed. These swellings on the lupin-roots, which were all on the main roots or thicker branches, are very different in appearance from the nodules on the pea and vetch-roots. They are, as described, swellings, incasing the root where they grow.

In pot 3, also with the lupin-soil-extract seeding, one plant developed an immense amount of branching root, with a great deal of root-fibre, which extended throughout the whole soil, but to a greater degree in the lower than in the upper half of the pot. The main root was woody near the top. The lower root-fibres were fleshy, and thickly coated with root-hairs. There were several swellings or nodules on the main root below 5 inches; and lower down, on a root-branch, there were several swellings; there being in all twelve on this plant. On the smaller and more meagrely rooted plant, about 10 inches down, there were also two bunches of small nodules, and three single nodules; and a little lower, on a side branch, another small nodule.

With regard to the great development of root-hairs on the fine fibrils of the roots in both pots 2 and 3, with quartz sand and soil-extract seeding, it may be supposed that this was an effort to acquire mineral nutriment, in quantity commensurate with the large amount of nitrogen fixed, and so rendered available to the plant.

In pot 4, with the lupin-soil itself, the distribution of root was very different from that in pots 2 and 3, with the soil-extract only. The main root, at a depth of 2 inches, threw out many thread-like branches, at the end of each of which there was a bundle of fine fibre. The lower fibres became thicker, and were white and fleshy; but they were without the marked development of root-hairs observed in such abundance in pots 2 and 3. Most of the root was within six inches of the surface, and there seemed to be none below 14 inches. One to two inches from the surface, there were swellings on the main roots, which were less raised, but more spreading, than those on the roots in pots 2 and 3. There were also, on one side branch, six very small nodules.

To sum up in regard to the yellow lupins: Under the influence of the lupin-soil-extract seeding, the above-ground growth was not only very luxuriant, but the plants developed great maturing tendency, flowering and seeding freely. The development of the roots generally, and that of swellings or nodules on them, were also very marked; and there can be no doubt that the gain of nitrogen will be found to be very large. In pot 4, with the lupin-sand itself, which would supply a not immaterial amount of combined nitrogen, although the growth was normal, it was, both above-ground and within the soil, very much less

than in the pots with soil-extract only; and the development of nodules was also less. It is possible that the less growth in the lupin-sand itself, than in the quartz-sand with soil-extract only, was partly due to the much less porosity of the lupin-soil, especially when watered. At any rate, the results with the soil-extract only are very remarkable.

The Experiments with Red Clover, in 1889-'90.

As the main growth of red clover is in the second year, the four pots of it were left for this year's growth. There is, therefore, at present but little of definite result available, but there are some points of interest to notice.

A photograph of the plants taken on September 28 (1889), showed that the above-ground growth in pot 1, without soil-extract, was decidedly more than in either pots 2 or 3 with it; and from the amount of growth that has since developed it is pretty certain that there is more than will be accounted for by the amount of nitrogen supplied in the seed sown. As the soil-extract seeding in pots 2 and 3 appeared to be without effect, a second amount of extract, this time from garden soil where clover was growing well, was applied to pot 2 on September 4; but to pot 3 there was added instead, a solution of calcium nitrate, and this application was continued up to December 6, when, in all, 0.23 gram of nitrogen had been so applied.

The effect of the nitrate was almost at once very striking; there being considerably increased growth, and coincidentally, increased depth of green colour. It was not, however, until many weeks later that the growth in pot 2, to which a second application of soil-extract had been made, became at all marked.

Two cuttings have been taken from each of the four pots, and the indication so far is that, in all, more dry substance has been produced in pot 2, with the second application of soil-extract, than in pot 3 with the nitrate. It remains to be seen what will be the final result. It should be added, and it is significant, that the amount of produce cut from pot 4, with garden soil, is many times as much as that from either of the other pots.

The Experiments with Lucerne, in 1889-'90.

In the case of lucerne, as in that of red clover, the main growth is subsequent to the first year, and hence the plants were left for further growth, indeed they are still growing.

The application of garden-soil-extract to the lucerne appeared to be entirely without effect up to the beginning of September (1889); the plants in pot 1 without soil-extract, and those in pots 2 and 3 with it, showing no difference, and apparently no progress. On September 4, therefore, pot 2 was re-seeded with soil-extract, this time from a soil growing lucerne; but to pot 3 a solution of calcium nitrate was added instead, and the application has been continued at intervals. As with the clover, so with the lucerne, the application of nitrate to pot 3 very soon

showed marked effect ; and a photograph taken on December 23 shows that there was, up to that date, considerably increased growth, and this has continued up to the present time. For many weeks, however, the second application of soil-extract was without any apparent effect, but subsequently there has been increased growth, and increased depth of green colour.

In pot 1, without soil-extract, the growth has been stationary since the first few weeks after sowing, and no cutting has been taken. From pot 2, with the repeated soil-extract seeding, a cutting was taken on June 24 (1890) ; and from pot 3 with the nitrate, and from pot 4 with the garden soil, cuttings were taken on March 4, and on June 24. At present there has been rather more produce removed from pot 3 with the nitrate, than from pot 2 with the soil-extract ; but from pot 4, as in the case of the clover, the garden soil has yielded considerably more than either the soil-extract or the nitrate.

Again, therefore, we have illustrated, the influence of soil supply of combined nitrogen on the growth of a leguminous plant ; the result being very marked whether the supply was as ready formed nitrate, or in the condition of combination and association with other constituents as in rich soil. Not that there is any want of abundant evidence showing that Leguminosæ do take up nitrogen largely as nitrate ; but, in view of recent results showing fixation under the influence of micro-organism seeding, it seems to be assumed by some that these plants probably depend for their nitrogen exclusively on such agency.

DIFFERENCE IN THE EXTERNAL CHARACTER OF LEGUMINOUS ROOT-NODULES.

The descriptions which have been given, have shown that the external appearance, and the distribution, of the root nodules, were very different in the case of the peas, the vetches, and the lupins. In that of the peas there were many of what may be called agglomerations of nodules, and comparatively few single ones distributed on the root-fibres. On the roots of the vetches, there were comparatively few agglomerations or bunches, and more single nodules, pretty widely distributed along the root-fibres. The lupin roots, on the other hand, showed tubercular developments very different from those on either the pea or the vetch roots. Indeed, at the period of examination, that is when the plants were nearly ripe, two apparently distinct kinds were observed ; one of which, the most prevalent, has been spoken of as "swellings," and the other as "nodules." The "swellings" were chiefly on the main roots or the thicker branches ; where they grew they encased the root entirely, and they had a shining and presumably impervious skin. The "nodules," on the other hand, were chiefly single, small, and distributed on the root-fibres.

Assuming that the so-called "swellings" (with their contents), on the roots of the lupins were the bodies which had exercised the functions of the "nodules" found on the roots of the other plants, it

is to be concluded that, after the very luxuriant growth, and the flowering and seeding, their function was so far at an end, and they had become suberised. The other bodies on the lupin roots, distinguished in the detailed description as "nodules," indicated too meagre development to have had much share in the great amount of assimilation that had been accomplished. On the other hand, the "swellings" which, as has been said, were all on the main roots or thicker branches, were certainly very characteristic of the roots of the lupin plants which attained the greatest growth; and, assuming that they with their contents were really the effective bodies, it must be supposed that they had been formed where they were found whilst the root was still young, and had grown with its growth. In favour of this supposition is the fact that the increased growth from the soil-extract seeding commenced quite early in the life of the plants.

The nodules on the roots of lucerne growing in the field were observed at different periods of the season in 1887, and again quite recently on plants taken from the field for that purpose. They are quite different in general external character from those on any of the other plants that have been examined at Rothamsted. Instead of being more or less rounded, they have more the appearance of shoots or buds, much longer than broad, sometimes single, but more often divided, or branched; there being generally two or three, and sometimes as many as twenty, or even many more, in a bunch, joined at the base. They have, so far, not been observed on the main root, but only on the root-fibres, and less near the surface than within the range of the subsoil. In some cases such a tuft or bunch will be at the end of a fine fibre, by which it is connected with the main root. As the season advances these bodies become shrivelled, and are in fact empty shells.

Among the Leguminosæ growing in the mixed herbage of grass land, in 1868 nodules were observed on the root-fibres of *Lathyrus pratensis*, especially near the surface of the soil; on the ultimate root-fibres of *Trifolium pratense*, and on the smaller rootlets of *Trifolium repens*.

In the case of red clover growing in rotation on arable land, an abundance of nodules has been found, both near the surface and at a considerable depth. They are generally more or less globular or oval. Some found on the main roots were more like "swellings" than attached tubercles, not, however, encasing the root, but only on one side. The greater number are, however, small, and distributed chiefly on the root-fibres. Evidence is, however, needed, as to any difference in character, or relative prevalence, at different periods in the life and growth of the plant, and under different conditions of soil, both so far as mechanical state and porosity, and richness or otherwise in available supplies of combined nitrogen, are concerned. To these points I shall refer again presently.

HOW IS THE FIXATION OF NITROGEN TO BE EXPLAINED?

Reviewing the whole of the results which have been brought

forward, there can be no doubt that they are abundantly confirmatory of those obtained by Hellriegel and Wilfarth, and that the fact of the fixation of free nitrogen in the growth of Leguminosæ under the influence of suitable microbe infection of the soil, and of the resulting nodule formation on the roots, may be considered as fully established.

It may be added, that B. Frank has continued his experiments on this subject; further that, in 1888, both M. Berthelot and M. Bréal made various experiments with Leguminosæ, and that their results also confirm those of Hellriegel and Wilfarth.

Admitting, then, the fact of fixation under the conditions described, the question still remains, how is it to be explained? Unfortunately, there is much yet to learn before a satisfactory answer can be given. Obviously we must know more of the nature and mode of life of the organisms which, in symbiosis with the leguminous plant, bring about the fixation of free nitrogen, before the nature of the action can be understood. As to the mode of life of these bodies, we owe much to the investigations of Marshall Ward, Prazmowski, Beyerinck, and others; but the facts which they have established so far, are insufficient to afford an adequate explanation of the phenomena involved.

It is, I think, a point of importance that it should be established, as it appears to be, that in the development of the parasite the cortex of the root of the host is penetrated, and so an intimate connexion between the two, indeed a symbiosis, is set up. Then there is abundant evidence that the nodules are very rich in nitrogen. So far as the facts at command go, it would seem that, in certain stages of their development, their dry substance may contain a much higher percentage of nitrogen than that of any part of the growing plant itself; and, in some cases at any rate, even higher than in that of the highly nitrogenous leguminous seed.

Whence comes this nitrogen? The views of those who have studied the histology and biology of the subject, without reference to quantitative chemical data, do not seem to be very clear or definite on the point. Thus, it has been assumed that the bacteria acquire their nutriment, including their nitrogen, from the protoplasmic cell-contents of the higher plant; and that, on the other hand, the contents of the bacteroid cells are resorbed. In other words, the plant utilises the substance of the bacteroids. It is obvious, however, that so far as the nitrogen of the bacteria is derived from the plant itself, the latter is not a gainer in a quantitative sense by its resorption.

It has further been assumed, that the activity of the process depends on the quantity of the nitrogenous compounds at the disposal of the roots; the tubercles developing unhindered, and becoming large and typical, in a soil rich in nitrogen, but attaining no great size in poorer soils. The source of the nitrogen of the bacteria is here supposed to be combined nitrogen in the soil. The experimental results which have been described clearly show, however, that the nodules may develop very plentifully in a nitrogen-free soil, and that

there may, under such conditions, be great gain of nitrogen if only the soil be suitably infected.

It is at the same time stated, that no decision is arrived at as to whether the nitrogen comes from nitrogen-compounds, or from the free nitrogen of the air, nor as to what advantage accrues to the bacteria and to the host plant respectively. It is, however, also stated, that the bacteria feed on the sap and cell-contents, whilst the plant obtains nitrogen by means of the bacteria. But, as I have already said, if the nitrogen of the bacteria is derived from the plant, it will itself be no gainer by resorbing it. Nor would there be any such actual gain of nitrogen in nitrogen-free soils as there undoubtedly is, if the source of the nitrogen, either of the parasite or of the host, were essentially the supplies of combined nitrogen within the soil.

Further, one assumption is, that the organisms become distributed in the soil, both during the life of the host and afterwards, and that the fixation takes place under their agency within the soil itself, rather than in the course of the development of the bacteria in symbiosis with the higher plant. Another assumption is, that the fixation takes place in the soil itself under the influence of microbes existing within it, and that the higher plant assimilates the resulting combined nitrogen. As bearing upon these points it may be observed that, in the experiments with peas in 1888, there was practically no gain of nitrogen within the soil itself, which it may be supposed there would have been if the fixation had taken place within it, and the host had acquired its gain from the compounds there produced. Indeed, the evidence at present at command certainly does not point to the conclusion that the gain of nitrogen by *Leguminosæ* under the influence of microbe infection of the soil, and nodule formation, is due to fixation by organisms within the soil itself, independently of the symbiotic life. It is admitted, however, that further evidence is needed on the point.

It is obvious, too, that so far as free nitrogen may be fixed by microbes within the soil independently of connection with a higher plant, the resulting nitrogenous compounds should, directly or indirectly, be available to plants generally, whether leguminous or non-leguminous.

On this point it may be remarked that about thirty years ago Boussingault concluded, from the results of vegetation experiments made in 1858 and 1859, in mixtures of rich soil and sand, that free nitrogen had been fixed within the soil by the agency of mycodermic vegetation, and that the nitrogenous products which remained within it were largely in the form of organic detritus. Subsequently, however, he considered that there was not satisfactory evidence that free nitrogen is fixed within the soil under the influence of the development of lower organisms. It is of interest to observe, however, that those of his results in 1858 and 1859 which showed any material gain of nitrogen, either in the vegetable matter grown or in the soil, were obtained with *Leguminosæ*; and that, in the case in which there was the greatest gain in the plants themselves, he records that there were numerous tubercles

on their roots. In one other case, in which however only sand was used as soil, and the gain in the plant was but small, he also observed tubercles on the roots. In the other cases of gain no mention is made of tubercles, and it may be that the roots were not so examined as to determine whether they existed or not. It is, at any rate, very significant, when viewed in the light of recently acquired knowledge, that in all the cases of gain the plants grown were of the leguminous family, and that in some of them nodules were observed on the roots.

On the other hand, Berthelot considers that he has experimentally proved the fixation of free nitrogen by the agency of microbes within the soil, both in the absence of higher vegetation, and also coincidentally with the growth of *non*-leguminous plants. He further considers that such fixation takes place to an extent which would be an important source of nitrogen to our crops. Whether or not this experimental result be eventually confirmed, it may safely be said, that neither experience in practical agriculture, nor the nitrogen statistics of soils and crops, points to the conclusion that our *non*-leguminous crops do acquire nitrogen rendered available by the fixation of free nitrogen under the agency of microbes within the soil independently of leguminous growth, or at any rate that they do so in any material degree.

In 1888, however, Berthelot made numerous experiments with Leguminosæ, and in many of them he found very large gains of nitrogen; indeed a much higher range of gain than in his other experiments. That there should be large gain under such conditions is quite consistent with the results which have been recorded of the experiments made at Rothamsted in 1888 and since, with Leguminosæ; and, like them, Berthelot's results contribute to the confirmation of those of Hellriegel and Wilfarth. Further, these results of Berthelot, like those obtained at Rothamsted and by others with leguminous plants, are consistent with well established facts of agricultural production, and with the nitrogen statistics of soils and crops, and serve, with them, to aid the solution of long recognised problems in connection with the growth of Leguminous crops.

But, whether or not it may eventually be established that nitrogen is fixed by microbes within the soil independently of leguminous growth, there is evidence that in soils and subsoils containing organic nitrogen, lower organisms may serve the higher plants, by taking up, or attacking and bringing into a more readily available condition, combined nitrogen not otherwise, or only very slowly, available for the higher plants. For example, it is probable that Fungi generally, derive nitrogen from organic nitrogen; and in the case of those of Fairy Rings there can be little doubt that they take up from the soil organic nitrogen which is not available to the meadow plants, and that, on their decay, their nitrogen becomes available to the associated herbage. Then in the case of the fungus mantle observed by Frank on the roots of certain trees, it may be supposed that the fungus takes up organic nitrogen, and so becomes the medium of the supply of the

soil nitrogen to the plant. More pertinent still is the action of the nitrifying organisms in rendering the organic nitrogen of the soil and subsoil available to the higher plants. It may well be supposed, therefore, that there may be other cases in which lower organisms may serve the higher, by bringing into a more available condition the combined nitrogen already existing, but in a comparatively inert state, in soils and subsoils.

As to the undoubted fixation of free nitrogen in the growth of leguminous crops under the influence of suitable microbe infection, and of the development of nodules on the roots of the plants, the alternative explanations seem to be :—

1. That the plant is enabled, under the conditions of the symbiosis, to fix the free nitrogen of the atmosphere by its leaves.

2. That the organisms become distributed within the soil and there fix free nitrogen ; the resulting nitrogenous compounds becoming available as a source of nitrogen to the roots of the higher plant.

3. That free nitrogen is fixed in the course of the development of the organisms within the nodules, and that the resulting nitrogenous compounds are absorbed and utilised by the host.

It seems to me that the balance of the evidence at present at command is much in favour of the third mode of explanation.

It must be admitted, however, that more evidence is needed as to the mode of life of the parasite, especially having regard to the surrounding media. The subject, in various aspects, is being further investigated at Rothamsted. Experiments have been made or are in progress to determine the amount of gain, if any, under the influence of soil-extract seeding, in the case of—peas, beans, vetches, lupins, white clover, red clover, sainfoin, and lucerne. It is obvious, however, that in the case of experiments conducted with a view to the analysis of the final products of growth, no examination of the roots of the plants, and of the nodule-formation on them, can take place until the conclusion of the experiment. Accordingly, a series of experiments has this year been arranged, in such manner as to admit of the careful examination of the roots at successive periods of the growth of the plants. The same eight descriptions of leguminous plant as above enumerated are thus under experiment. Each is grown in a comparatively pure, but unwashed and unsterilised sand, with soil-extract added ; and also in a mixture of rich garden soil and sand. It is obvious that, under such conditions, any difference in the character of the development of the roots, or of the nodules on them, on the one hand in an almost nitrogen-free but duly infected soil, and on the other in one rich in compounds of nitrogen, can advantageously be studied.

OF WHAT IMPORTANCE TO AGRICULTURE IS THE NEWLY-ESTABLISHED SOURCE OF NITROGEN TO LEGUMINOUS CROPS ?

The question yet remains :—What is the practical importance of this newly-established source of nitrogen to the Leguminosæ, considered

in its bearing on the known facts of Agricultural production, and especially on the question of the sources of the nitrogen, not only of Leguminous crops themselves, but of crops generally? Unfortunately, as in the matter of the explanation of the action by which the nitrogen is fixed, there is much yet to learn, before a satisfactory answer can be given. Still it may be well to report progress.

In our recent paper in the "*Philosophical Transactions*" (Vol. 180 B), we said that whilst experience, whether practical or experimental, did not point to an unsolved problem in the matter of the sources of the nitrogen of the agricultural plants of other families, it was quite otherwise so far as those of the Leguminosæ were concerned. It is true that both agricultural investigation, and direct vegetation experiment, have clearly shown that Leguminosæ do take up much soil-nitrogen, and, at any rate in great part, as nitrate. But it was admitted that, in some cases, there was no evidence to justify the conclusion that the whole of the nitrogen had been so derived; and hence, that some other explanation of the large amounts assimilated was needed.

It has been seen that the balance of experimental evidence is against the supposition that the higher plants growing under sterilised conditions can assimilate free-nitrogen. But, it is now established that, at any rate in the case of some leguminous plants, they may acquire nitrogen coincidentally with the development on their roots of tubercular bodies with bacteroid contents; and the evidence points to the conclusion, that it is the lower organisms, and not the higher plants, that fix free nitrogen.

It has been stated that the characteristic nodules have been found on the roots of various Leguminosæ growing among the mixed herbage of grass-land, and also on those of others growing on arable land, in the ordinary course of agriculture. It has been suggested, that when such plants are growing in soil and subsoil containing an abundance of combined nitrogen, lower organisms may serve the higher, at any rate in part, by bringing the already combined nitrogen of the soil and subsoil into a more readily available condition. But, so far as free nitrogen may be brought into combination, the question arises—under what conditions will this action come the more or the less into play?

As bearing upon this subject, it may be stated that, in experiments with beans, Professor Vines found that the formation of nodules on the roots was very much reduced, if not only accidental, when the plants were liberally supplied with nitrate. Again, in some of the experiments at Rothamsted which have been described, there was a less development of nodules when the soil contained an abundance of combined nitrogen. On the other hand, some observers have concluded that the development of the nodules is the greater, the greater the supply of nitrogenous compounds at the disposal of the roots; and, in some of the experiments at Rothamsted, this has undoubtedly been the case. It is admitted, however, that further evidence is required on the point, and it is believed that the experiments now in

progress, to which reference has been made, will afford some definite information on the subject.

It would seem not improbable that different Leguminosæ may behave differently in this respect. Should this prove to be the case, and supposing it be established that fixation of free nitrogen is always a coincident of the nodule development, it would be concluded that when nodules develop abundantly on the roots of Leguminous plants growing in soil rich in readily available combined nitrogen, the nitrogen assimilation will be largely due both to soil nitrogen and to fixation. On the other hand, it is clear, as in the case of the experiments with yellow lupins growing in nitrogen-free but duly-infected sand, for example, that the nitrogen assimilation may be very large in the absence of any initial soil supply beyond that in the seed sown. Obviously in such a case the assimilation will be almost entirely due to fixation.

Should the results of further investigation and observation confirm the indication that on the roots of some Leguminosæ nodules develop the more, and that there is coincidentally a greater gain of nitrogen due to fixation, the richer the soil in available combined nitrogen, whilst with others it is not so, or that there is at any rate great gain without such soil supply, it is obvious that the proportion in which a leguminous crop will derive its nitrogen, on the one hand from soil supplies of combined nitrogen, and on the other from fixation under the influence of the symbiotic life, may be very different, according to the peculiarities of the particular description of plant, and to the characters of the soil as to available supply of combined nitrogen, mechanical condition, and due infection.

SUMMARY AND CONCLUSION.

There is no evidence that the leguminous plant itself assimilates free nitrogen. The evidence at present at command, is in favour of the supposition that the observed gain is due to the fixation of nitrogen in the development of the lower organisms in the root-nodules, and that the nitrogenous compounds produced are taken up and utilised by the leguminous plant. Further, the development of the supposed nitrogen fixing bodies is obviously dependent on due infection with organisms essential to the setting up of the symbiotic life in the particular leguminous plant to be grown.

It seems probable that, in the growth in practical agriculture of leguminous crops, such as clover, vetches, peas, beans, lucerne, &c., at any rate some, and in some cases a considerable proportion, of the large amount of nitrogen which they contain, and of the large amount which they frequently leave as nitrogenous residue in the soil for future crops, may be due to free nitrogen so brought into combination by the agency of lower organisms.

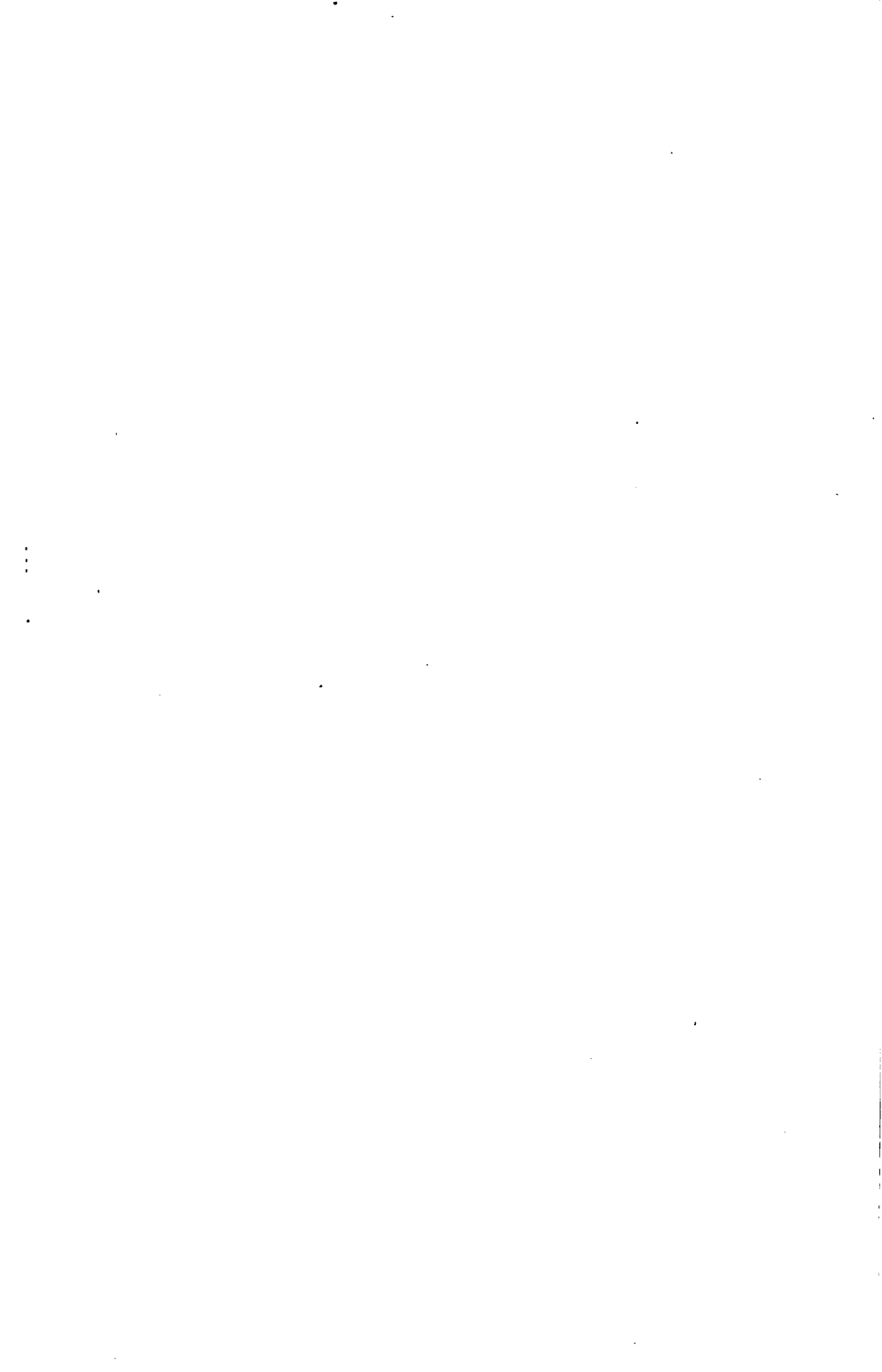
It has yet to be determined, under what conditions a greater or less proportion of the total nitrogen of the crop will be derived—on the one

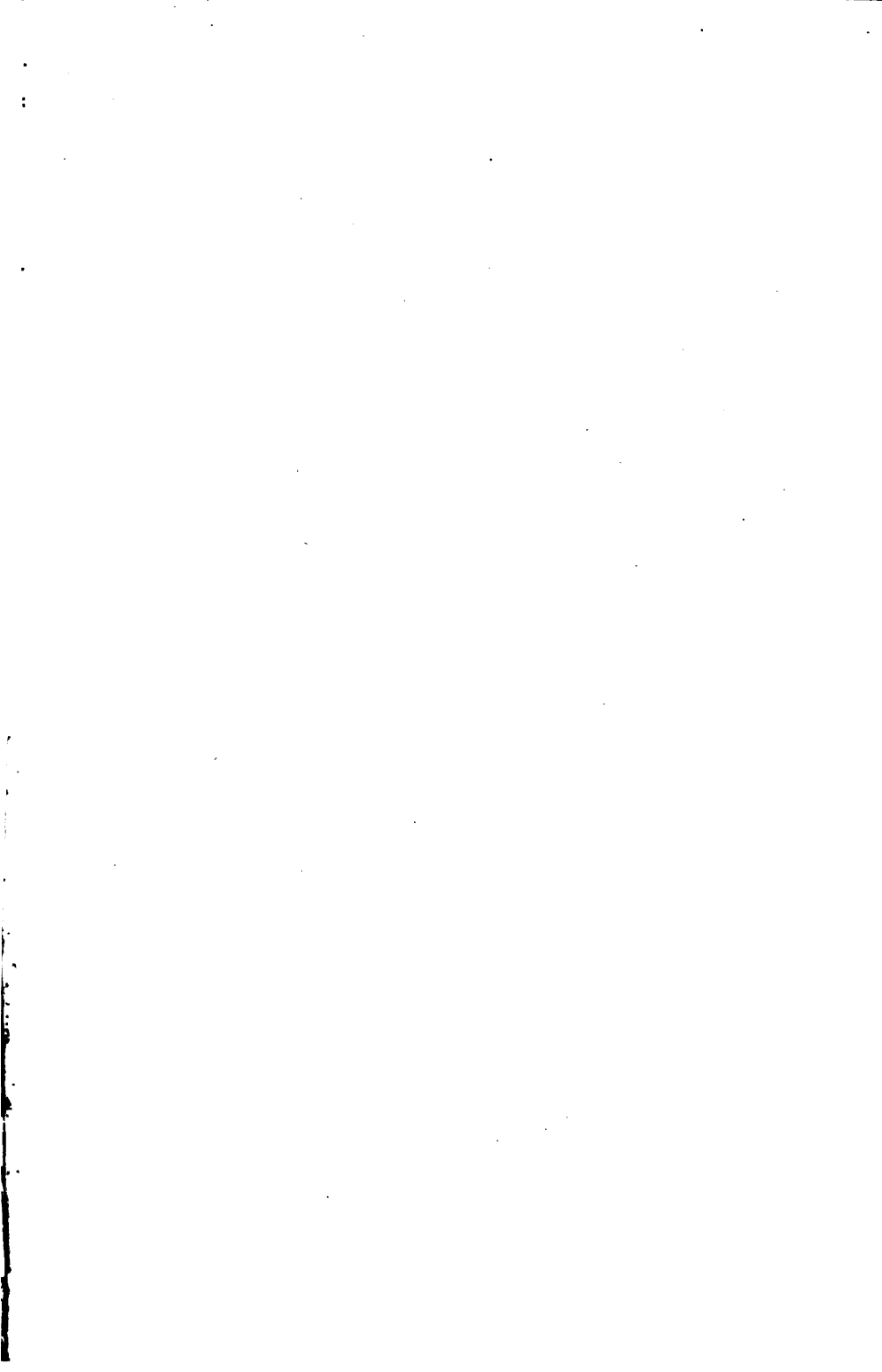
hand from nitrogen-compounds within the soil, and on the other from such fixation.

Incidentally the question suggests itself—how far the failure of red clover, or of other leguminous crops, may be due to the exhaustion of the organisms necessary for nodule development, and for the consequent fixation of free nitrogen, and how far to the exhaustion of combined nitrogen in an available condition, or of the necessary mineral constituents, within the range of the roots?

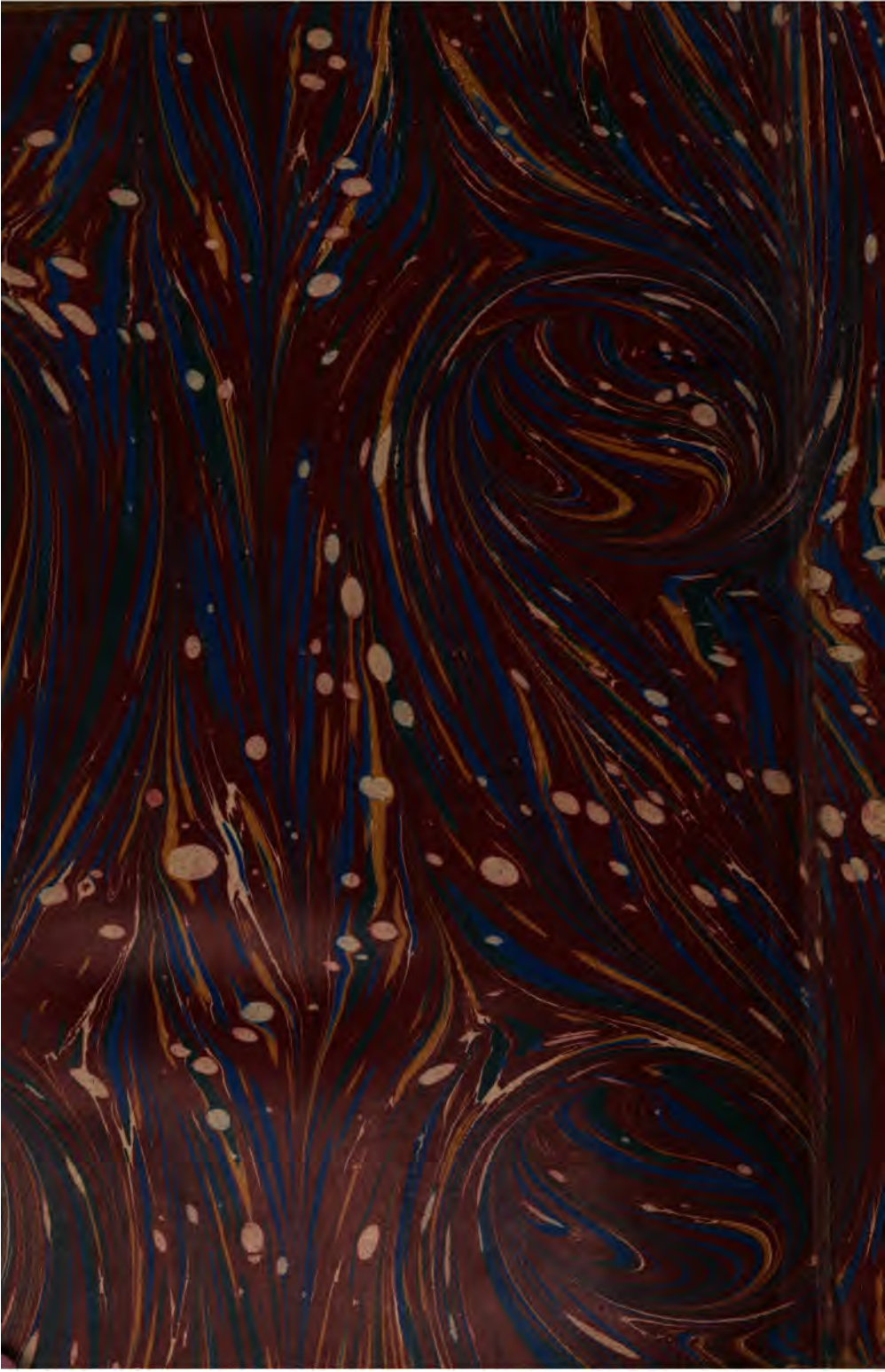
Assuming it to be established that a considerable proportion of the nitrogen of our leguminous crops is due to fixation under the conditions supposed, it is obvious that such a fact will not only serve to explain the source of the hitherto unaccounted for amount of the nitrogen of those crops themselves, but it will also aid the explanation of the source of the increased amount of nitrogen which other crops acquire, when they are grown in association, or in alternation, with Leguminosæ. Lastly, it will help to explain the source of part of the accumulated combined nitrogen within our soils, and the comparatively slow exhaustion of their stores of it, by cropping, drainage, and in other ways.











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